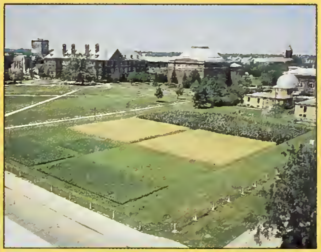
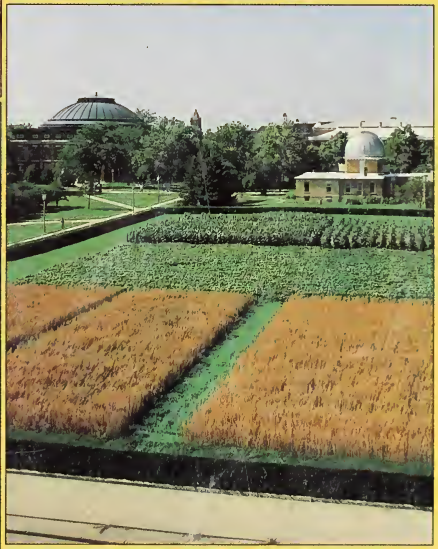
Illinois Agronomy Handbook
1995-1996

University of Illinois at Urbana-Champaign • College of Agriculture
Cooperative Extension Service • Circular 1333




Cover photos: The Morrow Plots at the University of Illinois at Urbana-Champaign. See page iv for details.

Agricultural Research and Demonstration Centers

☐ Research centers administered by the Department of Agronomy at the University of Illinois. Areas of research include agronomy, agricultural engineering, agricultural entomology, animal sciences, forestry, horticulture, and plant pathology.

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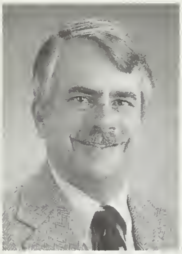
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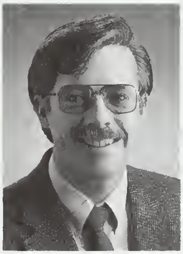
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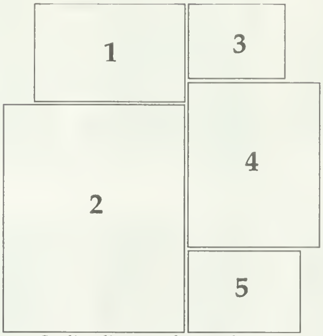
About the cover. . .The Morrow Plots, a 120-Year Continuous Experiment. . .



Outline diagram of cover photos.

The Morrow Plots were initiated in 1876 as a crop-rotation study. Although the plots were reduced in both number and size in 1903—and have been subdivided to facilitate soil fertility and other research variables—in 1995 corn will have grown for the 120th consecutive growing season at this historic site.

Of the original ten half-acre plots, only three plots remain, and each one has been reduced in size and subdivided into eight subplots. The rotations are: continuous corn, corn and soybean (corn-oats prior to 1968), and corn-oats-alfalfa. Because of the different crops, the individual whole plots can be seen clearly in Photos 2, 3, and 4 in the cover montage, and some subplots are also discernible.

Here are more details on the cover photos of the Morrow Plots and some of the stories they tell:

Photo No. 1. (From archival files, Information Services, Office of Agricultural Communications and Education, University of Illinois College of Agriculture.)

This is a late-summer photo taken in 1955. All plots are planted in corn, which occurs every 6 years. This was also the first crop year following the final subdivision of the Morrow Plots into 8 subplots, at a time when some new fertilizer treatments were being introduced. The fully grown corn obscures much of the visual effect of treatment on corn growth, although grain yields do vary widely among treatments.

Photo No. 2. (Taken by Jack Everly, Associate Professor, Agricultural Communications and Education, University of Illinois.)

This is a mid-summer 1960 shot from atop Mumford Hall which particularly shows the effect of different fertilizers on subplots in the alfalfa.

Photo No. 3. (Also taken by Jack Everly.) This shot, taken only a few hours after Photo No. 2, offers another vantage point, this time from atop the Animal Science Laboratory.

Photo No. 4. (Taken by David A. Riecks, Extension Communications Specialist, Photography, Office of Agricultural Communications and Education.)

This mid-summer 1992 photo shows corn, soybean, and oats. Of interest is the now-familiar yew hedge, which has replaced the perimeter fence, and the Undergraduate Library (just out of sight on the left), which was built—mostly below ground level—in 1965-67.

Photo No. 5. (From archival files, Information Services, Office of Agricultural Communications and Education, University of Illinois College of Agriculture.)

This mid-summer 1937 photo shows all plots in corn. Growth patterns show clearly the subdivision of each plot into quarters, with the south two quarters of each plot receiving fertilizer treatments, and the north halves receiving none.

Contents

Chapter 1.
Agricultural Climatology

Weather and climate

The year-to-year, day-to-day variation of weather complicates the scheduling of agricultural practices. However, the use of continuous weather observations, weather forecasts, and climate data may be used to schedule crop management practices for optimum benefit.

Accurate recording of weather conditions each year helps to indicate the current status of crop and pest development. The future development of crops and pests can be estimated using observed weather data related to current time, combined with past climate data and weather forecasts. Weather forecasts are available up to 90 days into the future, with forecast skill decreasing as the length of the forecast period increases and with a 90-day forecast the least reliable. Short-term forecasts (defined as those with a 12-hour period to those with a 5-day period) include information on anticipated temperature, rainfall, relative humidity, and winds. Longer-term forecasts (6 to 10-day, 30-day, and 90-day) are limited to indications of future temperature and precipitation.

Weather variables

Weather variables including air and soil temperatures, precipitation, humidity, solar radiation, soil moisture, and wind are measured on a frequent basis throughout the day, week, and month. Information gathered from these measurements are used to calculate other variables that are important to agriculture, such as evapotranspiration, growing degree days, heat and cold stress days, and days suitable for field work.

Although often viewed as the same products, weather and climate data are different. Weather data describe the state of the atmosphere at a specified time, whereas climate data are summaries of weather conditions over many years. Climate data reflect the mean and variation of weather conditions during given time periods. Climate data can be used to estimate the timing of biological events such as crop growth and crop, insect, and disease stages. These estimates can then be used to plan the timing of production practices.

The number of field work days available for completing spring and fall work is determined by the weather and plays a major role in limiting the number of acres a producer can farm. Therefore, a region's climate helps determine the size and number of tractors, combines, and tillage implements needed to complete field work in a timely manner.

This chapter discusses the importance of understanding the climate of Illinois as it relates to factors which influence the management of agricultural crops.

Climate variables

Temperature

The growing season is generally defined as the period between the last spring frost and the first fall frost. Most annual crops are planted after the major risk of frost or freeze has passed. However, late frosts — particularly very late frosts — can cause damage to both annual and perennial crops during the spring. Mean last dates of spring frosts occur as early as April 9 in southern Illinois and as late as May 4 in northern Illinois (Figure 1.01). In 1 out of every 10 years, the last spring frost can occur as early as March 27 or as late as April 24 in southern Illinois, and as early as April 21 or as late as May 14 in northern Illinois.

The average first fall frost dates range from October 6 in northern Illinois to October 21 in southern Illinois. In 1 out of 10 years, the first fall frost occurs by September 26 in northern Illinois and by October 6 in southern Illinois (Figure 1.02). In 9 out of 10 years, the first frost occurs before or on October 21 in northern Illinois and November 5 in southern Illinois.

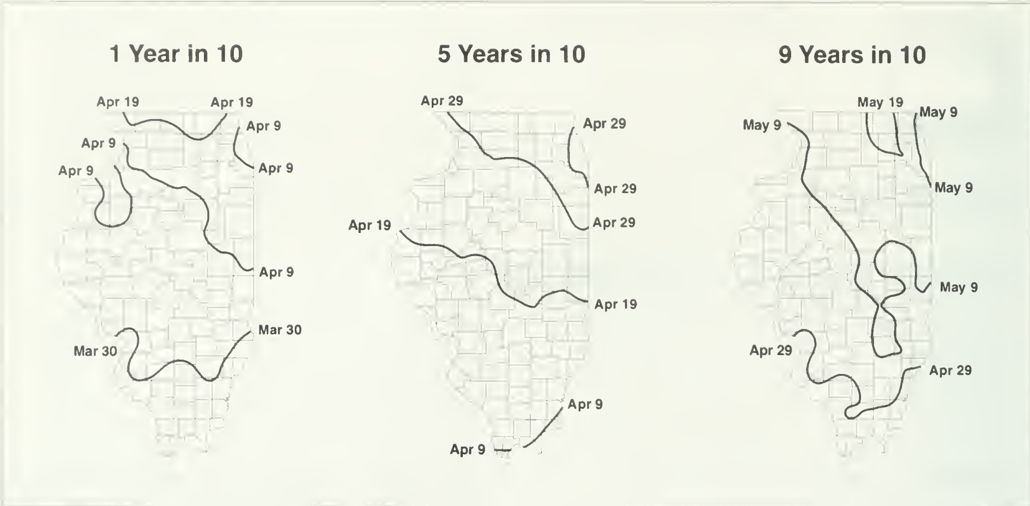


Figure 1.01. Probable dates of last spring frost (32°F minimum temperature).

Figure 1.02. Probable dates of first fall frost (32°F minimum temperature).

Mean minimum temperatures (°F) for Illinois range from the mid-teens to mid-twenties in winter to the low- to mid-sixties in the summer (Figure 1.03). Mean minimum temperatures during the spring and autumn range from the upper-thirties to mid-forties. Mean maximum temperatures range from the low-thirties to mid-forties during the winter. Summer mean maximum temperatures range from the low-eighties in the northern regions of Illinois to the high-eighties in the southern regions. Spring and autumn mean maximum temperatures range from the high-fifties to low-sixties in the northern regions, and in the mid- to high-sixties in the south. In the north, spring mean maximum temperatures tend to be cooler than mean maximum temperatures in the autumn.

Soil temperature. Soil temperatures in the autumn

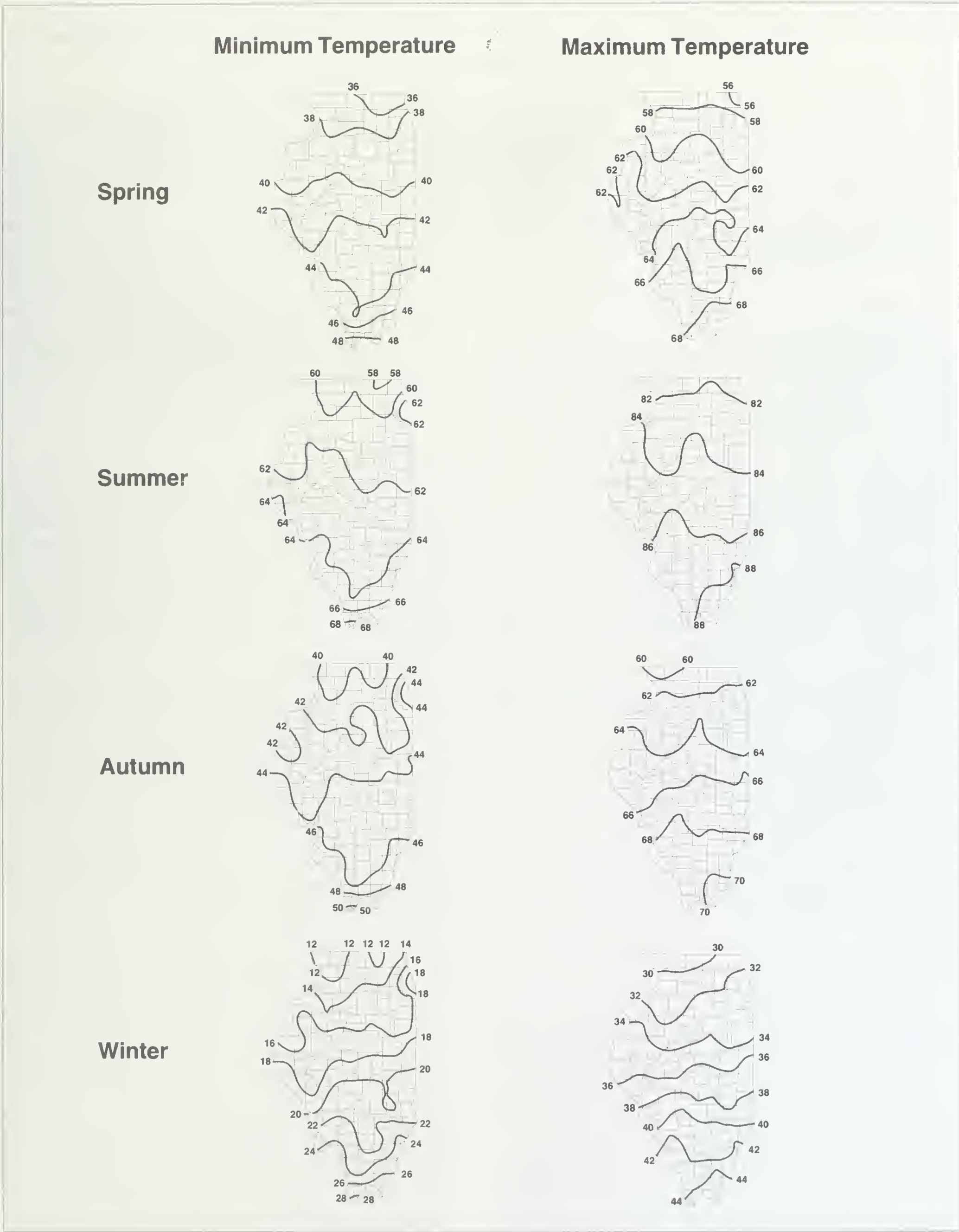


Figure 1.03. Mean maximum and minimum temperature for spring, summer, autumn, and winter.

determine when ammonium nitrogen fertilizer may be applied without excessive nitrification occurring during the autumn and winter. At soil temperatures below 50°F the rate of nitrification is reduced, but does not stop until temperatures are below 32°F. Soil temperatures throughout the state are below 50°F by mid-November, 9 years out of 10 (Figure 1.04). Maps showing the date when soil temperatures fall below 60°F are included as a guide for estimating when anhydrous ammonia application with a nitrification inhibitor can begin. As a rule of thumb, 50°F soil temperatures are observed 25 to 30 days after 60°F soil temperatures occur.

Precipitation

Precipitation type, timing, and amount received during the year play a critical role in the productivity of crops. Mean annual rainfall ranges from 36 inches of precipitation in the north to 45 inches of precipitation in the south (Figure 1.05). Annual rainfall of less than 28 inches of precipitation in the north and less than 34 inches of precipitation in the south can be expected 1 year out of 10. Annual rainfall can be expected to be greater than 46 inches of precipitation in the north and greater than 52 inches of precipitation in the south for an average of 1 year out of 10. Winter is the driest season, with approximately 5 inches of precipitation in the north and 10 inches of precipitation in the south (Figure 1.06). Spring is the wettest season in the south with more than 13 inches of rain, whereas summer is the wettest season in the north, with 12 inches of rain.

Rains greater than 0.10 inches often delay field work, especially in the spring and early summer when the soils are the wettest. On the average, there are 7 days each month with rainfall greater than 0.10 inches during April and May (Table 1.01), 6 days each in June and July, and 5 days each in August and September. The average rain amount in each storm is larger during the summer than during the spring (Table 1.01). Generally, the average number of rain days with 0.10 inches of rain in dry and wet years does not change more than 1 day from normal years; the major difference is in the amount of rain received in each storm.

Potential evapotranspiration

Evapotranspiration is the water removed from the soil by a combination of evaporation from the soil surface and transpiration (loss of water vapor) from the leaves of plants. Evaporation from the soil surface is limited to the upper 2 to 4 inches of soil, while transpiration results in removal of water from the soil to a depth equal to the deepest roots.

"Potential" evapotranspiration is the amount of water which would evaporate from the soil surface and from plants when the soil is at field capacity. Field capacity defines the amount of water the soil holds after it has been saturated and then drained until drainage virtually ceases. Soils drier than field capacity will result in an actual evapotranspiration less than the potential evapotranspiration, as will plant canopies that do not totally cover the soil.

Potential evapotranspiration is greatest in dry years with low humidity and predominantly clear skies and least in wet years with high humidity and cloudier than normal skies. Total potential evapotranspiration from April though September ranges from approximately 33 inches in dry years to about 27 inches in wet years. Actual evapotranspiration during wet years will equal the potential maximum, but will be less than the potential maximum in dry years. During the growing season the normal total monthly evapotranspiration is least in September, and greatest in June and July (Figure 1.07). Drought conditions occur when the potential evapotranspiration exceeds rainfall by more than the normal difference for several months in a row.

Soil moisture

The amount of water held in soil is determined by soil texture, soil drainage, precipitation, and evapotranspiration. During the summer months evapotranspiration generally exceeds the rain water absorbed by the soil, and the soil profile dries out. From October through April, evapotranspiration is less than precipitation and the soil profile is recharged. In Illinois, soils generally become saturated at some time in the spring.

Wet spring soils play an important role in determining how many days are suitable for spring field work. When soil moisture is normal or wetter than normal, even small rains will result in field work delays on all but the sandiest soils in Illinois. Excessive soil moisture in the late spring and early summer may result in loss of nitrogen through denitrification and leaching and may lead to the development of seed, root, and crown diseases. Conversely, dry soils during planting may result in poor stand establishment, and may cause plant stress when they occur during the periods of flowering and seed set.

The typical arable soil in Illinois is a silt loam or silty clay loam and will, on the average, hold approximately 7.5 inches of plant-available water in the top 40 inches of soil. Plant-available water is defined as the amount of water in the soil between field capacity and wilting point. In the uppermost 40 inches of soil, the average amount of water held by Illinois soils at field capacity is approximately 14 inches The wilting point is defined as the amount of water still in the soil when plants are unable to recover, during the night, from wilting during the day. Illinois soils hold approximately 6.5 inches of water in the upper 40 inches of soil at the wilting point. Water in the top 40 inches of soil at saturation is approximately 17.5 inches. Individual soils will vary significantly from the average. Coarse textured soils, such as sands, will hold less

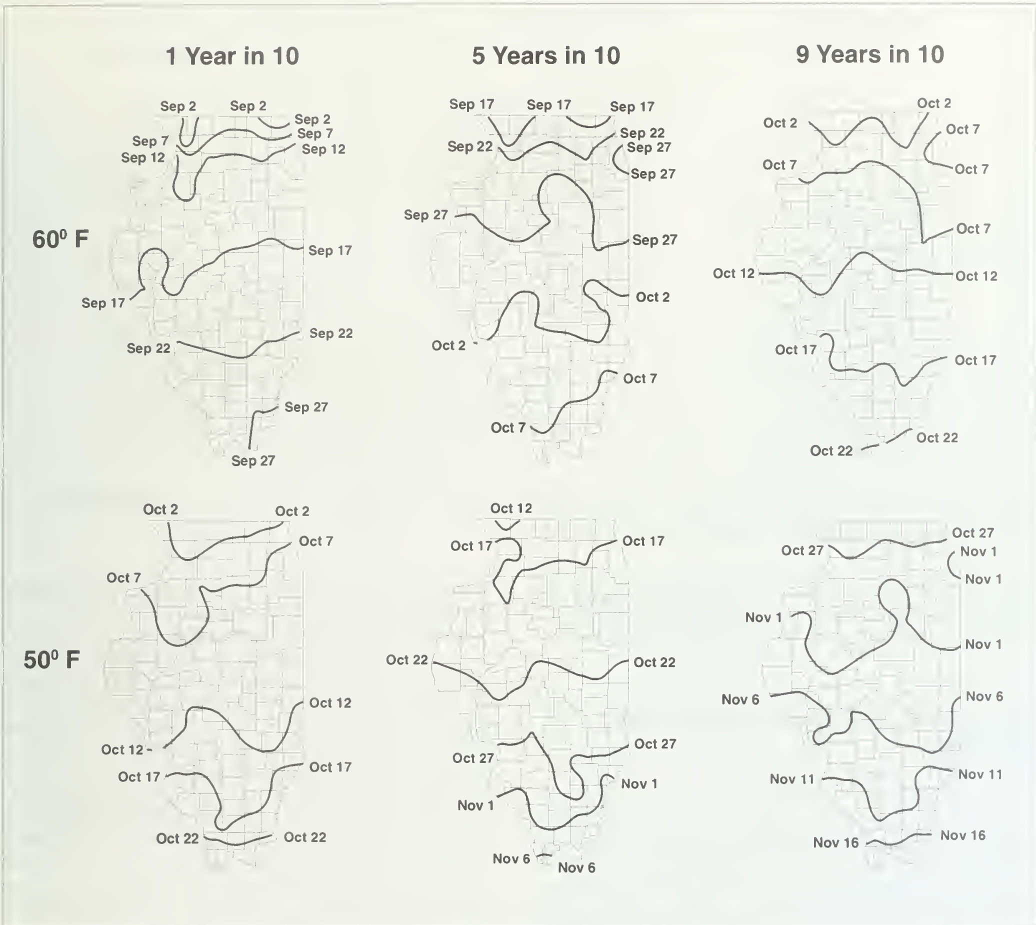


Figure 1.04. Probable first date in the fall when the 4-inch soil temperature drops below 60°F and 50°F.

water at the wilting point and field capacity than fine textured soils or soils with high clay content.

During the spring planting season, the amount of water in the top 6 inches of soil controls field work activities. When the top 6 inches of soil are wet, planting will be delayed, and nitrogen can be lost to either denitrification or leaching. Traffic or tillage on fields when soils are near field capacity (80 percent of saturation) causes maximum compaction. During average springs, soil moisture conditions in April are wet enough that rains greater than 0.3 inches will bring the soil water to field capacity (Table 1.02). In wettest years, rains greater than 0.3 inches will result in significant periods of near-saturated soils in the upper 6 inches. The rainfall amounts shown in Table 1.02 are the minimum amounts of rain needed to trigger denitrification and provide optimum compaction conditions. In cases when the subsurface soil levels are dry, more rain than the amounts shown is needed to have this effect. Only in the driest years will soils seldom reach field capacity.

Whenever plant-available water in the top 40 inches of soil is less than 3.8 inches during the period June through August, plants will show significant moisture stress during the day. Soil moisture is generally below this limit only during the driest months of July and August (Table 1.03). Even in these months, soils should experience some periods above this stress threshold,

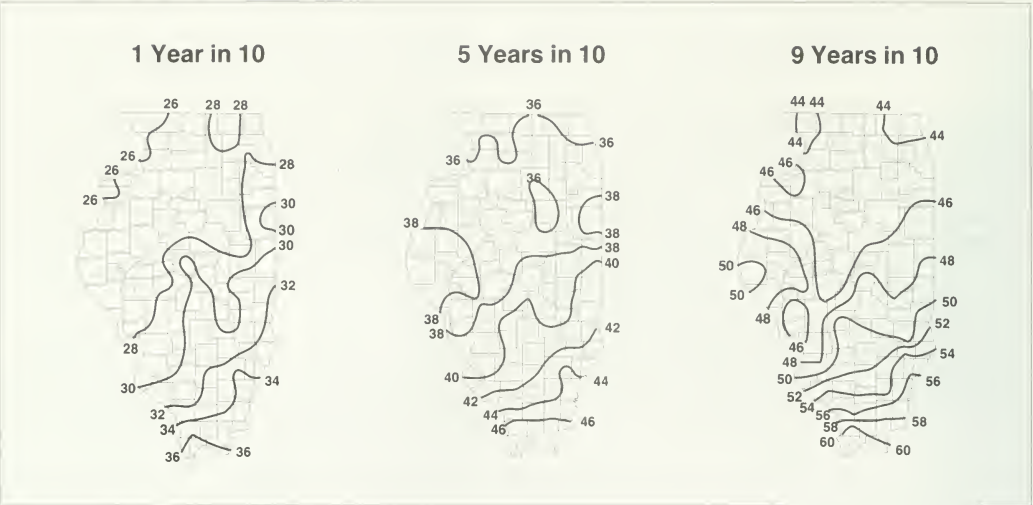


Figure 1.05. Probable annual rainfall amounts (inches).

especially following rains. In the wettest years, plant-available water exceeds plant needs, and periods of saturation may occur during the summer months.

Crop, insect, and disease environmental thresholds

Crop environmental thresholds

Crops are generally grown in regions where temperature and rainfall conditions favor their growth. In regions where temperature is favorable but natural rainfall is insufficient, crops are irrigated if sufficient water is available. Temperature is a major factor in determining where a specific crop is grown if natural rainfall or irrigation water is sufficient. Minimum, optimum, and maximum temperature ranges — called the "cardinal" ranges — for growth of the major crops in Illinois are presented in Table 1.04. The corresponding temperatures for photosynthesis are in most cases lower than those for growth. A combination of moisture stress and optimum temperature may result in some type of crop damage. For example, temperatures above 95°F during pollination of corn will result in a reduction of pollen viability and, therefore, a possible reduction in the number of kernels set. Moisture stress during this same period may result in delayed silk emergence and a further reduction in the number of kernels set.

There is little a producer can do to control temperatures across large areas. However, knowledge of how crops respond to temperature can be used to assess possible yield losses due to temperature stresses. These yield loss estimates can be used in planning marketing strategies or pest control procedures.

Growing degree day accumulation. Since temperature is a major determinant of the rate of crop development, growing degree days (GDD) have been used for many years to track the development rate of crops and to estimate the time of harvest. See Chapter 2 for a complete description of growing degree days. The GDD, also called growing degree units (GDU), is calculated by subtracting the lower temperature threshold (base temperature) from the daily mean temperature, then summing over days. Below the base temperature, or above the maximum temperature, the rate of development is negligible. For example, the base temperature for corn is 50°F. If the temperature is below 50°F, corn development is very slow. The development rate of corn and soybeans is also slowed when the maximum temperature exceeds 86°F.

Modern corn hybrids are rated by the number of GDD after planting necessary to reach maturity. GDD accumulations can be used to help select alternate corn hybrids in years when planting corn is delayed. In years when corn can be planted in late April, there is a greater than 95 percent chance (Figure 1.08) that more GDD are accumulated before the normal first frost date than are needed for maturing a 2,800 growing degree unit (GDU) corn hybrid in all of the state except the northern one-third of Illinois. If planting is delayed until late May, a 2,800-GDU corn hybrid has only a 5 to 10 percent chance of maturing before frost in northern Illinois, a 50 percent chance in central Illinois, and a 95 percent chance in extreme southern Illinois. A 2,400-GDU corn hybrid planted in late May has a 95 percent chance of maturing in the southern

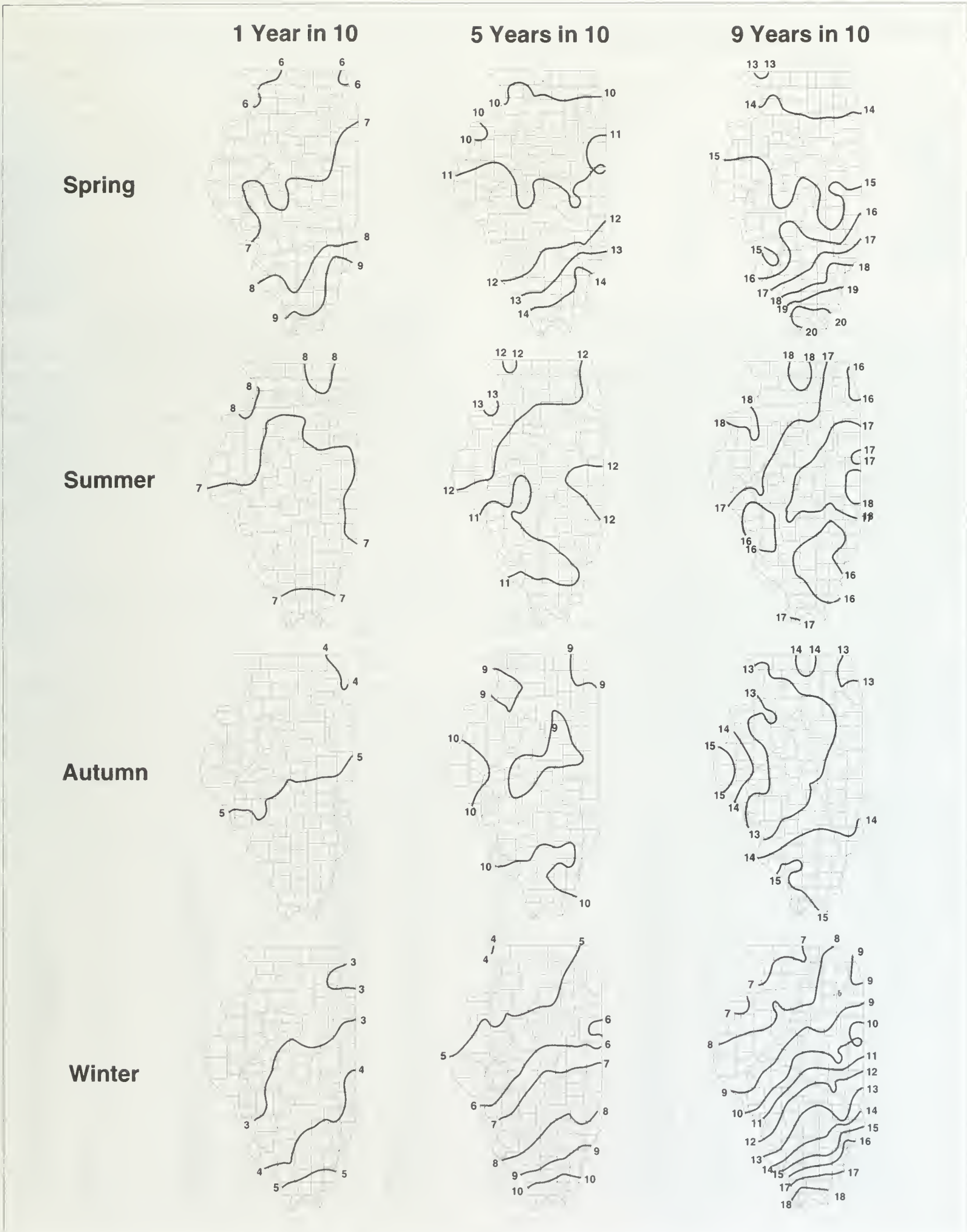


Figure 1.06. Probable seasonal rainfall amounts (inches).

Table 1.01. **Number of Days with Rain Amounts Greater Than 0.01 Inches and Average Storm Size**

Month	Days with rain > 0.01 in.	Average rain per storm (in.)		
		North	Central	South
April	7	0.53	0.54	0.64
May	7	0.54	0.59	0.70
June	6	0.68	0.65	0.65
July	6	0.65	0.68	0.72
August	5	0.80	0.68	0.64
September	5	0.76	0.72	0.64
October	5	0.52	0.56	0.60

one-half of the state, but only a 50 percent chance in the extreme northern part of Illinois.

Temperature stress. Crops begin to experience stress whenever the maximum or minimum temperature falls outside the range of optimum temperatures (Table 1.04). Heat stress days represent the frequency of daily maximum temperatures exceeding an optimum growing temperature. Cold stress days account for the frequency of daily minimum temperatures below some base temperature.

Most crops in Illinois will experience some degree of heat stress when maximum temperatures exceed 90°F. As maximum temperatures approach 100°F, crops experience significant heat stress, and yields are affected, especially if there is a moisture stress and the extreme maximum temperatures occur for an extended period. Heat stress degree days (sum of the Fahrenheit degrees by which the daily maximum temperature exceeds 90°F) provide a measure of the degree of high-temperature stress experienced by summer crops. Heat stress can begin to occur as early as May 17, and the chance of heat stress days continues until September 20 in the north and October 4 in the south (Figure 1.09). Chances of having heat stress days are at a maximum during the week of July 12 to 18.

Minimum temperatures below 50°F cause summer crops to experience cold stress. For soybeans, minimum temperatures below 50°F reduce the rate of photosynthesis on the following day. Maximum photosynthesis will not resume until a daily minimum temperature greater than 63°F occurs. Estimates of the effect of temperature below 50°F on summer crops are provided by the cold stress days. A cold stress degree day occurs when the minimum temperature is less than 50°F but

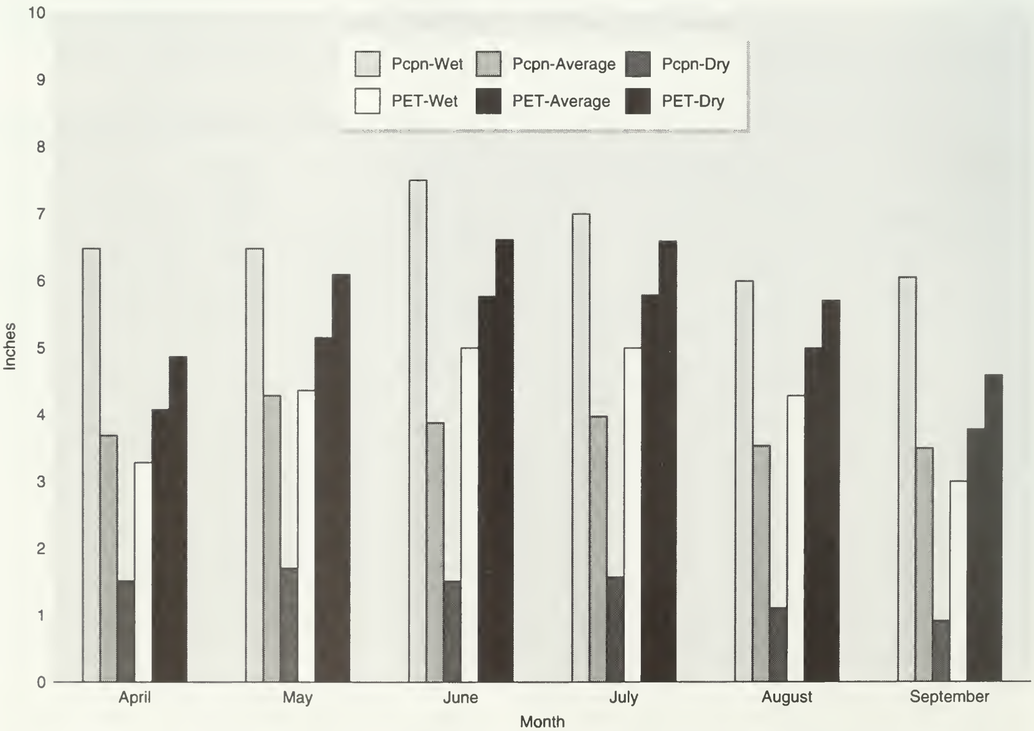


Figure 1.07. Total monthly potential evapotranspiration and precipitation during normal, wet, and dry years.

Table 1.02. **Soil Water Content in the Top 6-Inch Soil Layer of a Typical Illinois Silt Loam or Silty Clay Loam During April, May, and June, and the Minimum Rain Needed to Bring Soil Moisture to Field Capacity**

	Dry		Average		Wet	
Month	Water content (in.)	Rain needed to bring to field capacity (in.)	Water content (in.)	Rain needed to bring to field capacity (in.)	Water content (in.)	Rain needed to bring to field capacity (in.)
April	1.57	0.72	1.97	0.32	2.36	0.00
May	1.18	1.11	1.57	0.72	2.17	0.12
June	0.94	1.35	1.50	0.79	1.97	0.32

Table 1.03. **Plant Available Water in the Top 40-Inch Soil Layer of a Typical Illinois Silt Loam or Silty Clay Loam During June, July, and August**

	Plant-available water (in.)		
Month	Dry	Average	Wet
June	4.37	5.16	7.52
July	2.79	5.16	9.04
August	2.01	4.37	6.74

greater than 32°F. Cold stress days can occur as late as June 21 in southern Illinois and as late as July 5 in the north (Figure 1.09). Cold stress days begin to occur again by August 2 in the north and August 30 in the south.

Insect environmental thresholds

The development rate of insects and their ability to survive are closely connected to temperature. Insect development generally occurs only after the temperature is greater than the threshold temperature for a specific insect. An insect heat unit (IHU) is the difference between the mean air temperature and the threshold (base) temperature. IHUs are based on the same concept as GDU's, but with different base temperatures. Many insect growth stages have been correlated to IHUs. Therefore, IHUs can be used to estimate the start of field scouting of insects that overwinter in Illinois and begin development shortly after January 1. Survival temperatures, base development temperatures, and IHU accumulations for several important agronomic insects follow.

Alfalfa weevil. The alfalfa weevil (*Hypera postica*) begins growth and development at a temperature of 48°F. Eggs begin to hatch when approximately 200 base 48 IHUs have accumulated from January 1 (Table 1.05). Normally, temperatures cold enough to kill the early weevil larvae (Table 1.06) do not exist in Illinois after the accumulation of 200 to 300 base 48 IHUs. Larval survival rate is high at 54°F.

Nine years in 10, the alfalfa weevil egg hatch will begin by March 31 (Figure 1.10), and as early as March 1 in southern Illinois 1 year in 10. In northern Illinois alfalfa weevil egg hatch normally begins by April 20, but will start as early as April 10 (1 year in 10), and will be started by April 30 (9 years in 10).

Cereal leaf beetle. The cereal leaf beetle (*Oulema melanopus*) overwinters in diapause which is normally completed by mid-December. Therefore, IHU accumulations begin on January 1. The minimum, maximum, and optimum temperatures at which eggs will hatch, the survival temperature thresholds for different stages of the cereal leaf beetle (Table 1.06), and base 48°F growing degree day accumulations necessary to reach certain growth stages are shown in Table 1.05.

Egg-laying by the cereal leaf beetle begins (1 year in 10) as early as March 31 in southern Illinois and April 20 in northern Illinois (Figure 1.10). Nine years in 10, cereal leaf beetle egg-laying has started by April 20 in the south and by May 10 in the north.

Stalk borer. The stalk borer (*Papaipema nebris*) overwinters as an egg in Illinois and 50 percent egg hatch should be completed when approximately 278 base 48°F growing degree days have accumulated after January 1. First-generation adults emerge when approximately 3,670 IHUs (base 41.5°F IHUs) have been accumulated.

Egg-hatching of the stalk borer begins in northern Illinois approximately the same time as egg-laying by the cereal leaf beetle. However, the stalk borer egg hatch is 1 to 2 days behind the start of alfalfa weevil egg-hatching (Figure 1.10).

Bean leaf beetle. The development of the bean leaf beetle (*Cerotoma trifurcata*) can be estimated by accumulating IHUs above a base temperature of 45.5°F starting January 1. Bean leaf beetles overwinter as adults and begin emerging from winter habitats after 300 IHUs have accumulated. Bean leaf beetles can be found throughout Illinois. Excessively wet and dry soils result in reduced egg hatch numbers.

Black cutworm. Black cutworm moths (*Agrotis ipislon*) migrate into Illinois in the spring and lay eggs on winter annual weeds in corn fields. Eggs are generally laid before corn planting. Survival temperatures for black cutworm eggs, larvae, and adults are shown in Table 1.06. The development of black cutworm in Illinois can be estimated using a base 50°F IHU with accumulation beginning after the first intense black cutworm flight in the spring (Table 1.05). An intense flight is defined as 9 or more moths captured per trap

Table 1.04. Environmental Variable Thresholds of Different Growth Stages of Important Illinois Agronomic Crops

Crop	Growth stage	Temperature soil or air °F[a,b]	Minimum soil moisture bars[c]	Water use efficiency lb-H_2O/lb-dm[d]	Solar radiation for maximum growth % full sun
Alfalfa	Planting to emergence	Mn 34 Op 86 Mx 100	−12 to −15		
	Dormancy	Mn −4			
	Growing season	Mn 32-50 Op 50-86 Mx 86-104		993	60
Corn	Planting to emergence	Mn 46-50 Op 90-95 Mx 104-110	−10 to −12		
	Growing season	Mn 50-59 Op 86-90 Mx 104-122		388	90
Small grains	Planting to emergence	Mn 37-41 Op 59-81 Mx 86-104	−15 to −20		
	Growing season	Mn 32-50 Op 50-86 Mx 86-104		613	60
Sorghum	Planting to emergence	Mn 46-50 Op 90-95 Mx 104-110	−8 10 −15		
	Growing season	Mn 50-59 Op 86-104 Mx 104-122		402	90
Soybean	Planting to emergence	Mn 48 Op 80-90 Mx 108	−7		
	Growing season	Mn 50-59 Op 80-90 Mx 104-122		704	60
Grass pasture	Dormancy				
	Growing season	Mn 32-50 Op 50-86 Mx 86-104			40

[a] Soil temperatures from planting to emergence.
[b] Air temperature during growing season.
[c] Soil moisture.
[d] Water use efficiency.

over a 1 or 2 day period. Plant-cutting begins when 300 base 50°F IHUs have accumulated since an intense flight. The projected beginning black cutworm cutting dates are published in the *Pest Management and Crop Development Bulletin.*

Corn earworm. The corn earworm (*Helicoverpa zea*) is also a migrant into Illinois. Therefore, growing degree day accumulations must begin only after arrival of adult moths. The base temperature for IHU accumulation is 54°F, and egg hatch generally occurs after 77 base 54°F IHUs have accumulated (Table 1.05) after egg-laying.

European corn borer. Adult moths from the overwintering European corn borer larvae (*Ostrinia nubilalis*) begin to emerge after approximately 420 base 50°F IHUs have accumulated since January 1 (Table 1.05). Egg hatch begins approximately 100 IHUs after the eggs are laid or approximately 736 IHUs from January 1. Egg survival is reduced when maximum temperatures exceed 97°F (Table 1.06). The first instar larvae have a difficult time surviving when maximum temperatures exceed 90°F.

Moths from the overwintering European corn borer begin to appear as early as April 10 (1 year in 10) in southern Illinois (Figure 1.11) and by May 5 in northern Illinois. Adults from the overwintering generation have begun to emerge by April 30 in the south and by May 20 in the north (9 years in 10). These dates mark the

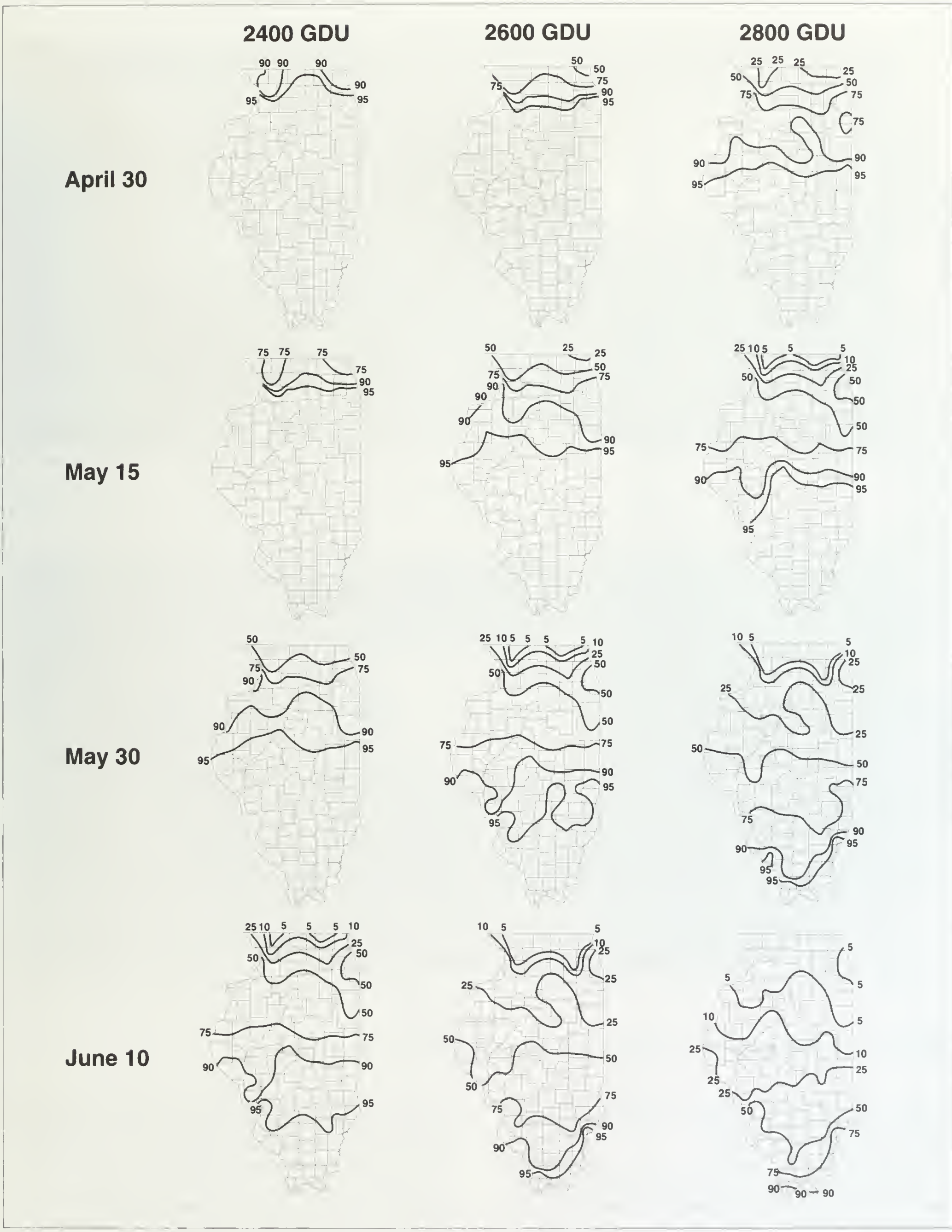


Figure 1.08. Probability of accumulating enough growing degree units (GDU) to mature corn hybrids with different maturity ratings.

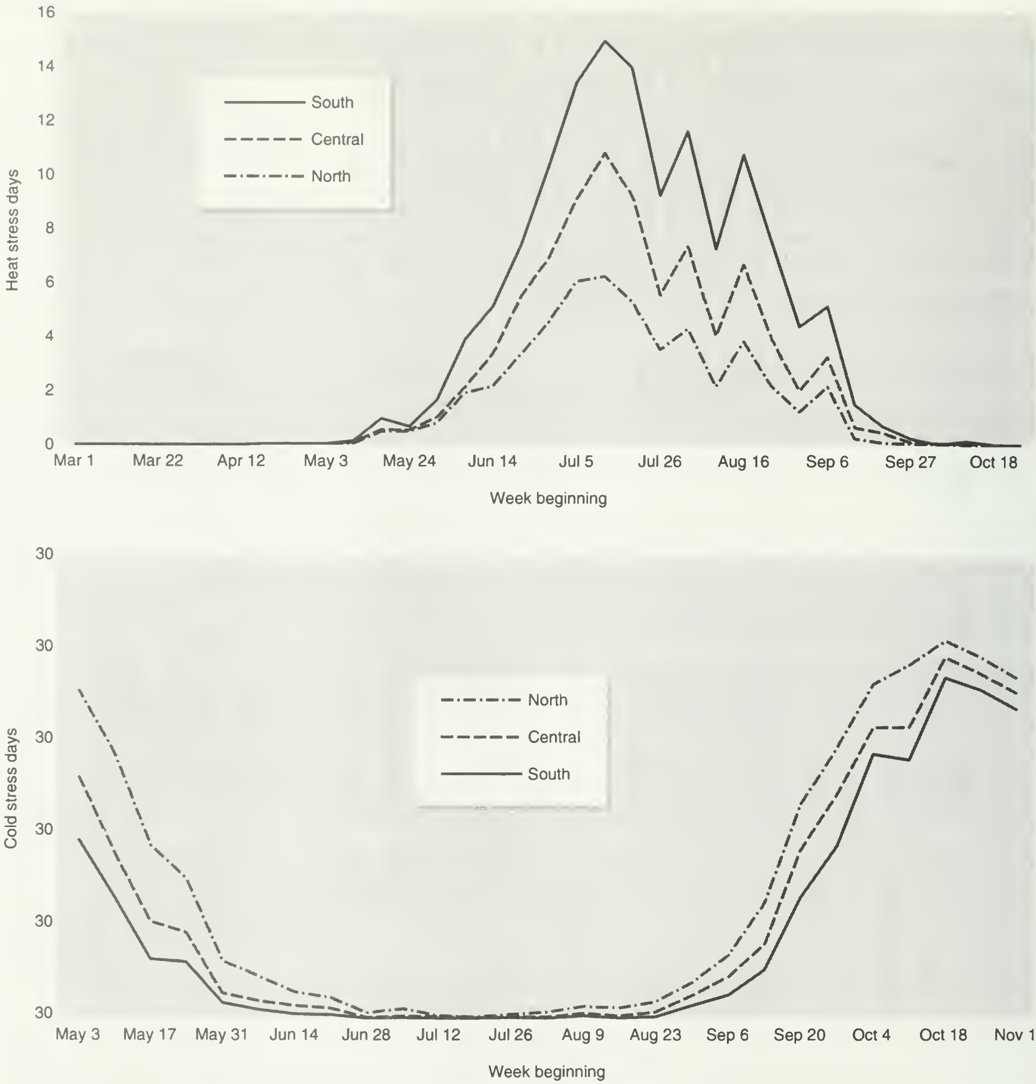


Figure 1.09. Mean heat and cold stress days experienced by summer crops in Illinois.

start of the appearance of the first flight of adults. Adults will continue to emerge for one to two weeks after the earliest appearance.

Corn flea beetle. The overwintering adult corn flea beetle (*Chaetocnema pulicaria*) becomes active after 270 base 61°F IHUs have accumulated from January 1. Large populations of the corn flea beetle may be expected when the December, January, and February average temperature is greater than 33°F. Small populations may be expected if the December, January, and February mean temperature is less than 27°F.

The corn flea beetle reaches the adult stage as early as April 20 in the south and May 10 in the north (1 year in 10, Figure 1.12). Nine years in 10, the corn

Table 1.05. Insect Heat Units (IHU) Required to Reach Various Insect Stages for Some Important Agronomic Insects in Illinois

Insect	Base temp. (°F)	First flight	Egg	First instar	Second instar	Third instar	Fourth instar	Pupae	Adult
Alfalfa weevil	48		200	270	340	407	497	587	810
Cereal leaf beetle	48		450	607	668	722	785	853	1,274
Black cutworm	50		90	146	200	280	330	610	960
Corn earworm	54		77					360	756
European corn borer	50	423	736	844	969	1,139	1,287	1,520	1,748

Table 1.06. Minimum, Maximum, and Optimum Temperatures in °F for Some Insects that Attack Agronomic Crops in Illinois

Insect	Temp.	Egg	First instar	Second instar	Third instar	Fourth instar	Fifth instar	Pupae	Adult
Alfalfa weevil	Mn	−11	−2	3	14	17		25	
	Op	90	90	90	90	86		86	
	Mx								95
Cereal leaf beetle	Mn	43	46					46	41
	Op	54-90						57-86	
	Mx	93	93					90	
Black cutworm	Mn	−4	41	41				23	23
European corn borer	Mn				18	13	−8		
	Mx	97	90						

flea beetle reaches the adult stage by May 20 in the south and June 9 in the north. Normally, the adult stage of the corn flea beetle is reached by April 30 in the south, May 15 in central Illinois, and May 25 in the north.

Environmental conditions affecting plant diseases

Disease infestations are influenced by both temperature and humidity. Some diseases occur under warm, humid conditions, others under hot, dry conditions. Thresholds that define hot, warm, cool, and cold growing-season temperatures, and high, moderate, and low humidity conditions are presented in Table 1.07. These data can be used in conjunction with climate maps and the *Field Crop Scouting Manual* to evaluate the risks of disease in a given area. When coupled with weather conditions during the current year and climate probabilities, estimates of disease risk for a given year may be obtained along with the probable time of disease expression.

Mean daily relative humidities exceeding 85 percent favor the development of many diseases. Normally, there are 2 to 3 days each month when the mean daily relative humidity exceeds 85 percent (Table 1.08). In August and September, an east-west relative humidity gradient exists, with a greater number of days with mean daily relative humidity exceeding 85 percent occurring in the western part of the state. July is a transition month, with the highest number of days with mean daily relative humidity greater than 85 percent occurring in the west central region.

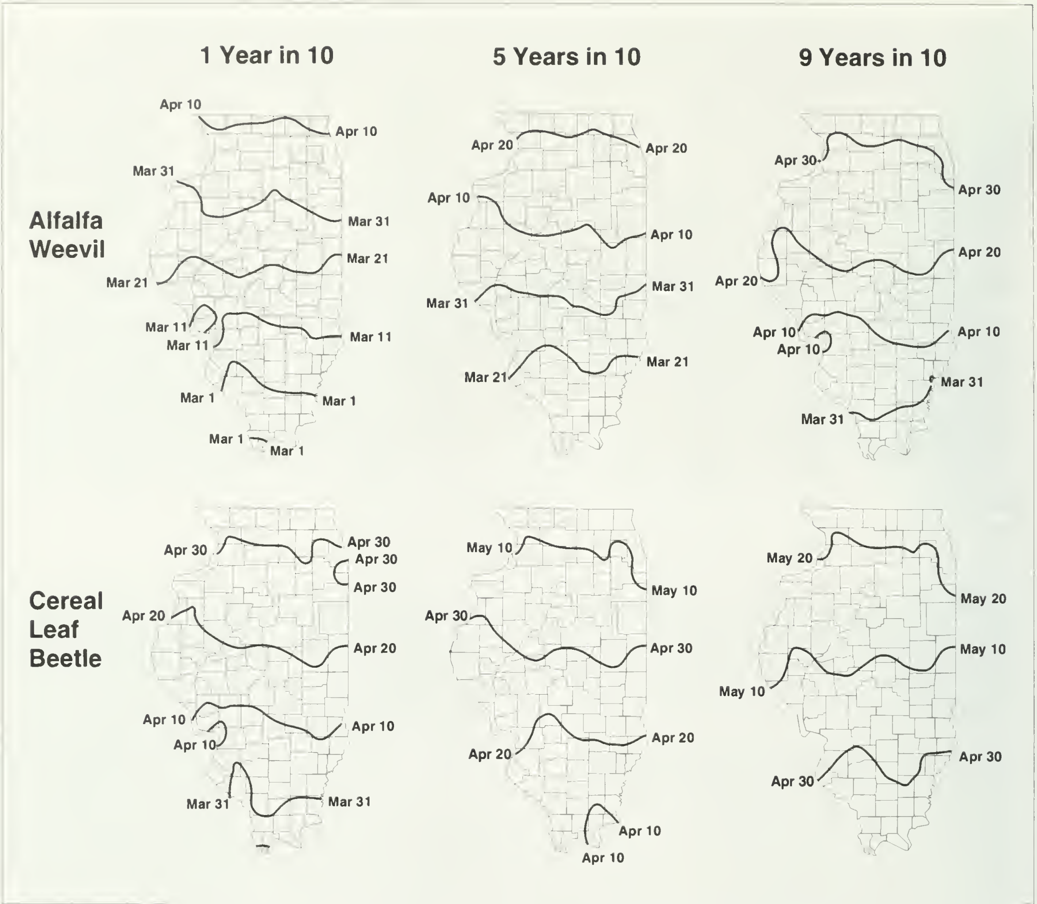


Figure 1.10. Probable dates when scouting for alfalfa weevil and cereal leaf beetle should begin.

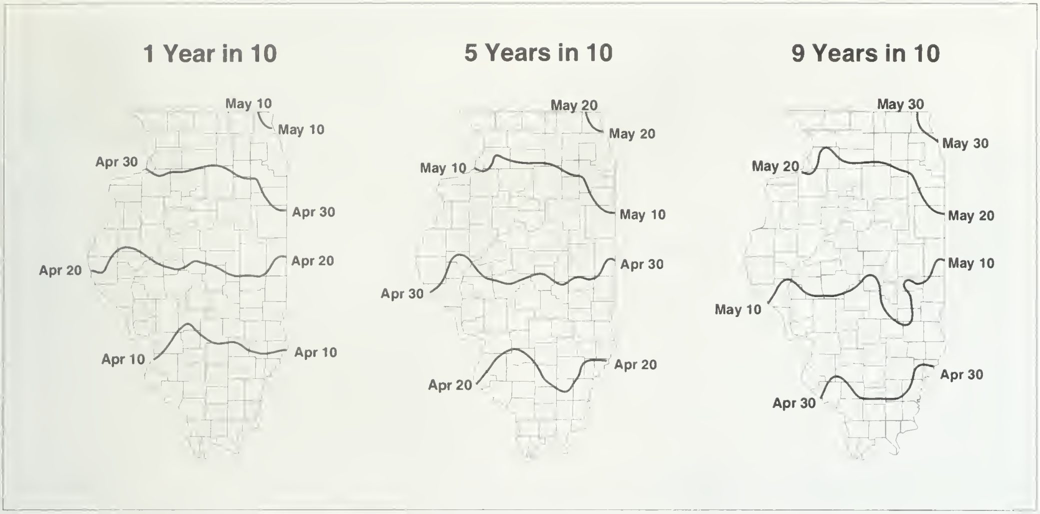


Figure 1.11. Probable dates of the first appearance of the adult European corn borer.

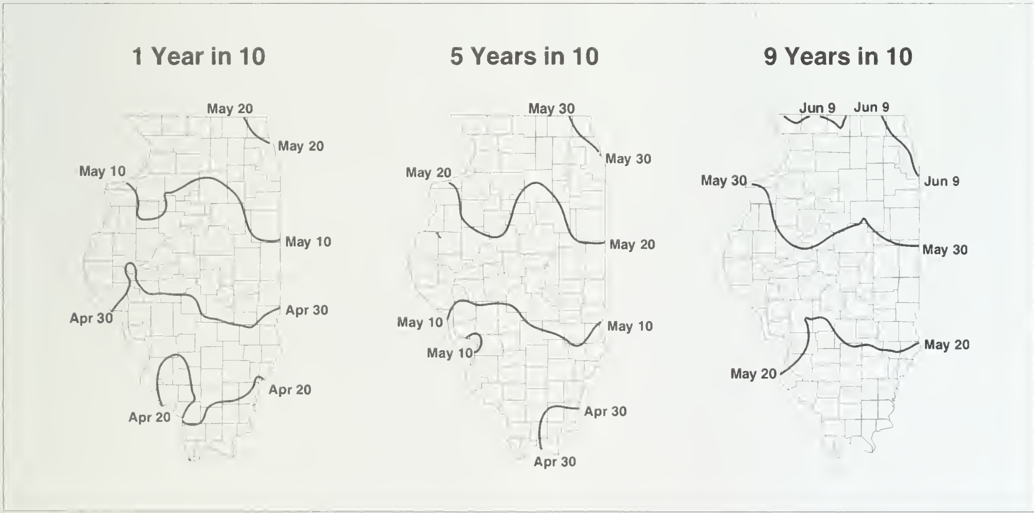


Figure 1.12. Probable dates of first appearance of corn flea beetle.

Table 1.07. Mean Daily Temperatures Describing Hot, Warm, Cool, and Cold Temperatures, and Mean Relative Humidity Describing High, Moderate, and Low Humidity Conditions During the Growing Season in Illinois

Temperature condition	Temperature (°F)	Humidity conditions	Relative humidity (%)
Hot	>82	High	>85
Warm	72-82	Moderate	50-85
Cool	59-71	Low	<50
Cold	<59		

Table 1.08. Number of Days per Month with Daily Mean Relative Humidity Exceeding 85 Percent During the Summer Crop Growing Season

	Days per month with daily mean relative humidity ≥ 85 percent		
Month	1 Year in 10	5 Years in 10	9 Years in 10
April	2	3	4
May	2	3	4
June	1	2	3
July	1	2	3
August	2	2	3
September	3	3	4

Chapter 2.

Corn

Yield goals

Management decisions are made more easily if the corn producer has set realistic yield goals based on the soil, climate, and available equipment. Usually it is not realistic, for example, to set yield goals of 180 bushels per acre for a soil rated to produce only 100 bushels per acre and from which the highest yield ever produced was 130 bushels per acre. Instead, managing to achieve a realistic yield goal should result in yields greater than the goal in years when conditions are better than average and reduced losses when the weather is unfavorable. The yield goal should be considered an *average*; it will not guarantee high yields when the weather is poor.

The first step in establishing a yield goal is a thorough examination of the soil type. Information for each soil type, such as the productivity ratings given in *Soils of Illinois* (Bulletin 778), can be a useful guideline. This information, however, should be supplemented by 3- to 5-year yield records, county average yields, and the yields on neighboring farms. An attempt should be made to ignore short-term weather and to set a goal based on long-term temperature and rainfall patterns.

Perhaps the simplest way to set a yield goal is to ignore the highest yield and lowest yield for the past 5 or 6 years and average the remaining yields. More than one low yield can be ignored, and more years used, if the average seems too low for a particular field.

Hybrid selection

When tested under uniform conditions, the range in yields among available hybrids is often 30 to 50 bushels per acre. Thus it pays to spend some time choosing the best hybrids. Maturity, yield for that maturity, standability, and disease resistance are the most important factors to consider when making this choice.

Concern exists with what many consider to be a lack of genetic diversity among commercially available hybrids. Although it is true that a limited number of genetic pools, or populations, were used to produce today's hybrids, it is important to realize that these pools contain a tremendous amount of genetic diversity. Even after many years of breeding, there is no evidence that this diversity has been fully exploited. In fact, a number of studies have shown that breeding progress is not slowed even after a large number of cycles of selection. Continued improvements in most desirable traits are evidence that this is true. Many of today's hybrids are substantially better than those that are only a few years old. For this reason, some producers feel that a hybrid "plays out" within a few years. Actually, the performance of a given hybrid remains constant over the years; but comparison with newer and better hybrids may make it appear to have declined in yielding ability.

Despite considerable genetic diversity, it is still possible to buy the same hybrid from several different companies. This happens when different companies buy inbreds from a foundation seed company that has a successful breeding program, or when hybrid seed is purchased on the wholesale market, then resold under a company label. In either case, hybrids are being sold on a nonexclusive basis, and many companies simply put their own name and number on the bags of seed.

Many producers, however, would like to avoid planting all of their acres to the same hybrid. One way is to buy from only one company, though this may not be the best strategy if it discourages looking at the whole range of available hybrids. Another way of assuring genetic diversity is to use hybrids with

several different maturities. Finally, many dealers have at least some idea of what hybrids are very similar or identical and can provide such information if asked.

It is also important to remember that genetics are only part of the performance potential of any hybrid. The way with which hybrid seed is produced — the care in detasseling, harvesting, drying, grading, testing, and handling — can and does have a substantial effect on its performance. Be certain that the seed being bought was produced in a professional manner.

Maturity is one of the important characteristics used in choosing a hybrid. Hybrids that use most of the growing season to mature generally produce higher yields than those that mature more quickly. The latest-maturing hybrid should reach maturity at least 2 weeks before the average date of the first killing freeze (32°F), which occurs about October 8 in northern Illinois, October 18 in central Illinois, and October 25 in southern Illinois. Physiological maturity is reached when kernel moisture is 30 to 35 percent and is easily identified by the appearance of a black layer on the base of the kernel where it attaches to the cob. The approach to maturity also can be monitored by checking the "milk line," which moves from the crown to the base of the kernel as starch is deposited. The kernel is mature about the time this milk line disappears at the base of the kernel.

Although full-season hybrids generally produce the highest yields, most producers choose hybrids of several different maturities. This practice allows harvest to start earlier and also reduces the risk of stress damage by lengthening the pollination period.

Comparing hybrid maturities may be difficult because there is no uniform way of describing this characteristic. Some companies use days to maturity, whereas others use growing degree days (GDD). Use of growing degree days is becoming more widely accepted, and it is usually possible to obtain a GDD measurement for any hybrid. This is done either directly or by comparing maturity with a hybrid for which GDD is known.

The following formula can be used to calculate GDD accumulated on any given day:

$$GDD = \frac{H + L}{2} - 50°F$$

where H is the high temperature for the day (but no higher than 86°F) and L is the low temperature (but no lower than 50°F). For example (see the following table), if the daily high temperature were 95°F, substitute 86°F, the cutoff point for high temperatures. If the daily low temperature were 40°F, substitute 50°F, the cutoff point for low temperatures. These high and low cutoff temperatures are used because growth rates do not increase above 86°F, and they do not decrease below 50°F.

The following figures are examples of daily high and low temperatures and the resulting GDD, calculated using the GDD formula:

Daily temperature		
High	Low	GDD
80	60	20
60	40	5
95	70	28
50	35	0

It is useful to keep a running total of daily GDD because GDD has been found useful in predicting the rate of development of the corn plant. For a full-season hybrid grown in central Illinois, the following table gives the approximate GDD required to reach certain growth stages:

Stage	GDD
Emergence	120
Two-leaf	200
Six-leaf (tassel initiation)	475
Ten-leaf	740
Fourteen-leaf	1,000
Tassel emergence	1,150
Silking	1,400
Dough stage	1,925
Dented	2,450
Physiological maturity (black layer)	2,700

These GDD numbers will vary with hybrid maturity. The relative proportion of full-season GDD required to reach each growth stage will, however, remain relatively constant. For example, GDD to silking will generally be about one-half of the GDD to physiological maturity.

A full-season hybrid for a particular area will generally mature in several hundred fewer GDD than the number given in Figure 2.01. Thus, a full-season hybrid for northern Illinois would be one that matures in about 2,500 GDD, while for southern Illinois a hybrid that matures in 2,900 to 3,000 GDD would be considered full season. This GDD "cushion" reduces the risk of frost damage and also allows some flexibility in planting time; it may not be necessary to replace a full-season hybrid with one maturing in fewer GDD unless planting is delayed until late May.

After yield and maturity, resistance to lodging is probably the next most important factor in choosing a hybrid. Because large ears tend to draw nutrients from the stalk, some of the highest-yielding hybrids also have a tendency to lodge. Such hybrids may be profitable because of their high yields, but they should be closely watched as they reach maturity. If lodging begins, or if stalks become soft and weak (as determined by pinching or pushing on stalks), then harvesting these fields should begin early.

Resistance to diseases and resistance to insects are important characteristics in a corn hybrid. Leaf diseases are easiest to spot, but stalks also should be checked for diseases. Resistance to insects such as the European corn borer also is being incorporated into modern hybrids. Another useful trait is the ability of the hybrid to emerge under cool soil conditions, a trait that is especially important in reduced- or zero-till planting.

With the large number of hybrids being sold, it is difficult to choose the best one. An important source of information on hybrid performance is the annual

report *Performance of Commercial Corn Hybrids in Illinois,* which is published as a newspaper insert in late fall, and is available in Extension offices. This summary reports hybrid tests run each year in nine Illinois locations and includes information from the previous 2 years. The report gives data on yields, kernel moisture, and lodging of hybrids. Other sources of information include your own tests and tests conducted by seed companies, neighbors, and Extension personnel.

Producers should see the results of as many tests as possible before choosing a hybrid. Good performance for more than one year is an important criterion. Hybrid choice should not be based on the results of only one "strip test." Such a test uses only one strip of each hybrid; the difference between two hybrids may therefore be due to location in the field rather than to an actual genetic difference.

Planting date

Long-term studies show that the best time to plant corn in Illinois is the last week of April, with little or no yield loss when planting is within a week on either side of this period. Weather and soil conditions permitting, planting should begin sometime before this date to allow for days when fieldwork is impossible (Table 2.01). Corn that is planted 10 days or 2 weeks before the optimum date may not yield quite as much as that planted on or near the optimum period, but it may often yield more than that planted 2 weeks or more after the optimum period (Table 2.02).

In general, yields will decline slowly as planting is delayed up to May 10. From May 10 to May 20, the yield will decline about one-half bushel for each day that planting is delayed. This loss will increase to 1 to 1½ bushels per day from May 20 to June 1, with greater reductions in northern Illinois than in the southern part of the state. After June 1, yields decline very sharply with delays in planting. The latest practical date to plant corn ranges from about June 15 in northern Illinois to July 1 in southern Illinois. If you plant this late, expect only 50 percent of the normal yield.

Early planting results in drier corn in the fall, allows for more control over the planting date, and allows for a greater choice of maturity in hybrids. In addition, if the first crop is damaged, the decision to replant can often be made early enough to allow use of the first-choice hybrid. Of course, early planting has some disadvantages: (1) cold, wet soil may produce a poor stand; (2) weed control may be more difficult; and (3) plants may suffer from frost. Improved seed vigor, seed treatments, and herbicides have greatly reduced the first two hazards; and the fact that the growing point of the corn plant remains below the soil surface for 2 to 3 weeks after emergence minimizes the third hazard. Because it is below the surface, this part of the plant is seldom damaged by cold weather unless the soil freezes. Even when corn is frosted, therefore,

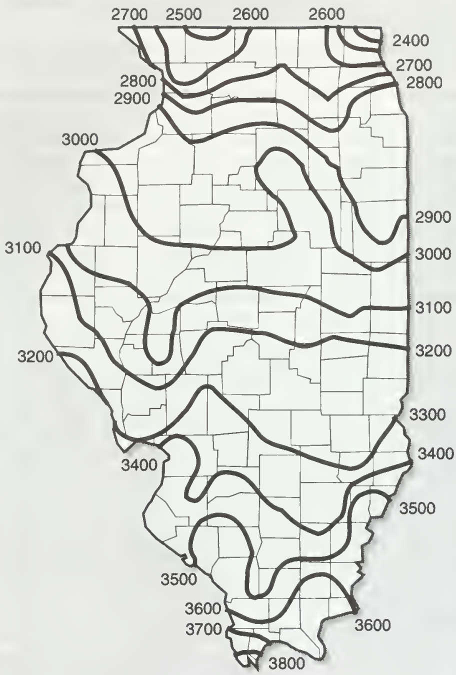


Figure 2.01. Average number of growing degree days (base 50°F from May 1 through September 30) based on temperature data provided by the Midwestern Climate Center, 1961–1990.

Table 2.01. Days Available and Percent of Calendar Days Available for Field Operations in Illinois[a]

	Northern Illinois		Central Illinois		Southern Illinois	
Period	Days	%	Days	%	Days	%
April 1-20[b]......	5.8	(29)	4.2	(21)	2.6	(13)
April 21-30[c].....	3.5	(35)	3.1	(31)	2.6	(26)
May 1-10[c]	5.8	(58)	4.3	(43)	3.5	(35)
May 11-20[c]	5.5	(55)	5.0	(50)	4.4	(44)
May 21-30[c]	7.4	(74)	5.8	(58)	5.4	(54)
May 31-June 9[c]..	6.0	(60)	5.4	(54)	5.6	(56)
June 10-19[c]	6.0	(60)	5.4	(54)	5.8	(58)

[a] Summary prepared by R.A. Hinton, Department of Agricultural Economics of the University of Illinois Cooperative Crop Reporting Service, unpublished official estimates of Favorable Work Days, 1955-1975. The summary is the mean of favorable days omitting Sundays, less one standard error, representing the days available 5 years out of 6.
[b] 20 days
[c] 10 days

the probability of regrowth is excellent. For these reasons, the advantages of early planting outweigh the disadvantages.

The lowest temperature at which corn will germinate is about 50°F. You should know what the soil temperature is, either from your own measurement or from reported measurements that are taken beneath bare soil. Soil temperature, however, is not the only consideration in deciding when to start planting. A more important consideration may be the condition of the soil: It generally is a mistake to till and plant when soils are wet, and the advantages of early planting may well be lost to soil compaction and other problems associated with "mudding in" corn, whether using conventional tillage or no-till techniques. If the weather conditions have been warm and dry enough to result in workable soils by early April, then planting can probably begin by April 10 or 15 with little danger of loss. The weather may change after planting, however, and a return to average temperatures (as happened in 1992) will mean slow growth for corn planted this early. It may be desirable to increase seeding rates by 1,000 to 2,000 seeds per acre if planting in April, mainly to allow for greater losses and to take advantage of the more favorable growing conditions that the crop is likely to encounter. Recent research shows little change in optimum plant population when planting time ranges from mid-April through early May (Figure 2.02).

With typical spring weather, soils can be tilled in preparation for corn planting to begin sometime around the middle of April. Delays due to low soil temperature (below 50°F) should be considered only if the weather outlook is for continued cold air temperatures. After April 20, soil temperature should probably be ignored as a factor, and corn should be planted as soon as soil conditions allow. Low-lying areas (such as river bottoms) may be planted last, because they warm up more slowly and are more prone to late freezes.

When planting begins in April, it is generally best to plant very full-season hybrids first, but planting the midseason and early hybrids in sequence tends to "stack" the times of pollination and harvest of the different maturities. It is probably better to alternate between early and midseason hybrids after the full-season hybrids are planted. This will help to spread both pollination risks and the time of harvest.

Planting depth

Ideal planting depth varies with soil and weather conditions. Emergence will be more rapid from relatively shallow-planted corn; therefore, early planting should not be as deep as later planting. For normal conditions, an ideal depth is 1½ to 2 inches. Early planted corn should be in the shallower end of this range. Later in the season, when temperatures are higher and evaporation is greater, planting as much

Table 2.02. Effect of Planting Date on Yield[a]

	Northern Illinois	Central Illinois	Southern Illinois
	bushels per acre		
Late April	...	156	102
Early May	151	162	105
Mid-May	150	...	82
Early June	100	133	58

[a] 3-year average at each location.

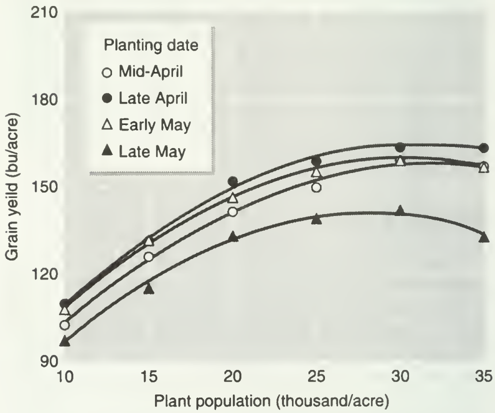


Figure 2.02. Response of corn planted at different times to plant population.
NOTE: Data are averages of two hybrids planted at two locations (Monmouth and DeKalb) for 4 years.

as 2½ to 3 inches deep to reach moist soil may be advantageous.

Depth-of-planting studies show not only that fewer plants emerge when planted deep but also that those emerging often take longer to reach the pollinating stage and may have higher moisture in the fall.

Plant population

The goal at planting time is the highest population per acre that can be supported with normal rainfall without excessive lodging, barren plants, or pollination problems. One way to know when the plant population in a field is near the optimum is to check the field for average ear weight. Check at maturity, or estimate by counting kernels (number of rows multiplied by number of kernels per row) once the kernel number is set. Most studies in Illinois suggest that the optimum plant population will produce ears weighing about one-half pound and having about 640 kernels. A half-pound ear should shell out about 0.4 pound of grain at 15 percent moisture.

The data shown in Figure 2.02 were used to generate Table 2.03, which gives expected yield at different plant populations planted on different dates. One

Table 2.03. Percentage of Maximum Yield Expected from Planting on Different Dates and at Different Plant Populations. Data Were Generated from the Results Shown in Figure 1.02

Planting date	Plant population per acre										
	10,000	12,500	15,000	17,500	20,000	22,500	25,000	27,500	30,000	32,500	35,000
	% of maximum yield expected										
April 10	62	70	76	82	86	90	92	94	94	94	93
April 15	65	73	79	84	89	92	95	97	97	97	95
April 20	67	74	81	86	91	94	97	98	99	99	97
April 25	68	75	82	87	92	95	98	99	100	100	98
April 30	68	75	82	87	92	95	98	99	100	100	98
May 4	67	75	81	86	91	94	97	99	99	99	97
May 9	65	63	79	85	89	93	95	97	97	97	96
May 14	63	70	76	82	86	90	92	94	95	94	93
May 19	59	66	73	78	83	86	89	90	91	91	89
May 24	54	62	68	74	78	82	84	86	86	86	85
May 29	49	56	63	68	73	76	79	80	81	80	79

important finding in this study was that the plant population that produced the highest yield did not change with the planting date; there is no reason to increase or decrease plant population when planting early or late, except that higher percentages of seeds may establish plants with later planting, thus the number of seeds dropped may be decreased a bit when planting is late. The data in this table can be used to make replanting decisions (see replanting section below), but the latest planting in this study was late May, so effects of replanting in June cannot be accurately determined from this project. Note that the highest yields were from populations around 30,000 per acre, which in this study produced ears with less than 0.4 pound of grain on average. Though the eight trials combined here were not always high-yielding (the study included the drought year of 1988), there is little reason to decrease plant populations below the upper 20,000s under productive conditions, at least in the northern half of the state.

The optimum population for a particular field is influenced by several factors, some of which can be controlled and some of which are difficult or impossible to control. Concentrate on those factors that can be controlled. For instance, little will affect the amount of water available to the crop during the growing season. This variable is determined by the soil type and the total amount and distribution of the rainfall between the time the crop is planted and when it is mature. It is possible, however, to influence how efficiently this water is used. The more efficient its use, the higher the population that can be supported with the water that is available. Remember that ear number is generally more important than ear size.

Two very important controllable factors influencing the efficiency of water use are soil fertility and weeds. Keep the fertility level of the soil high and the weed population low.

Other factors that are important include:

1. **Hybrid selection.** Hybrids differ in their tolerance to the stress of high populations. Most modern hybrids can, however, tolerate populations of 23,000 to 25,000 per acre on most Illinois soils. Some need even higher populations — up to 30,000 per acre — to produce the best yields, especially on more productive soils.
2. **Planting date.** Early planting enables the plant to produce more of its vegetative growth during the long days of summer and to finish pollinating before the hot, dry weather that is normal for late July and early August. Early planting usually produces larger root systems as well. In the study reported in Figure 2.02 and Table 2.03, however, planting date had little effect on optimum plant population.
3. **Row spacing.** The more uniform distribution of plants grown in narrow rows improves the efficiency of water use.
4. **Insect and disease control.**

The harvest population is always less than the number of seeds planted. Insects, diseases, adverse soil conditions, and other hazards take their toll. Expect from 10 to 20 percent fewer plants at harvest than seeds planted (Table 2.04).

Row spacing

Because of the clear yield advantage from using a row spacing of less than 40 inches, many producers have reduced row spacing; more than 50 percent of the corn acres in Illinois are planted in 30-inch rows, and the average row spacing in the state is about 33 inches. A few producers in the Corn Belt use rows less than 30 inches apart. Most studies have shown yield increases of about 5 to 8 percent when rows are narrowed from 30 to 20 inches (Table 2.05). You can expect the response to narrow rows to be greater with short hybrids than with tall, leafy hybrids that form a full canopy even in wider rows. Equipment for harvesting 20-inch rows is not readily available at present, but some harvesting equipment can be modified for this purpose.

Replanting

Although it is normal that 10 to 15 percent of planted seeds fail to establish healthy plants, additional

Table 2.04. Planting Rate That Allows for a 15 Percent Loss from Planting to Harvest

Plants per acre at harvest	Seeds per acre at planting time
16,000	18,800
18,000	21,200
20,000	23,500
22,000	25,900
24,000	28,200
26,000	30,600
28,000	33,000
30,000	35,300

Table 2.05. Corn Yields in 20- and 30-Inch Rows at Urbana

	Row width	
Plants per acre	30 inches	20 inches
	bushels per acre	
20,000	165	174
25,000	172	188
30,000	174	187

stand losses due to insects, frost, hail, flooding, or poor seedbed conditions may call for a decision on whether or not to replant a field. The first rule in such a case is not to make a hasty decision. Corn plants can and often will outgrow leaf damage, especially when the growing point, or tip of the stem, is protected beneath the soil surface or up until about the six-leaf stage. If new leaf growth appears within a few days after the injury, then the plant is likely to survive and produce normal yields.

When deciding whether to replant a field, assemble the following information: (1) original planting date; (2) possible replanting date and expected plant stand; and (3) cost of seed and pest control for replanting.

To estimate stand after injury, count the number of living plants in $\frac{1}{1,000}$ of an acre (Table 2.06). Take counts as needed to get a good average, one count for every 2 to 3 acres.

When the necessary information on stands and planting and replanting dates has been assembled, use Table 2.03 to determine both the loss in yield to be expected from the stand reduction and the yield expected if the field is replanted.

To use Table 2.03, locate the expected yield of the reduced plant stand by reading across from the original planting date to the plant stand after injury. Then locate the expected replant yield by reading across from the expected replanting date to the stand that would be replanted. The difference between these numbers is the percentage yield increase (or decrease) to be expected from replanting. For example, corn that was planted on April 25, but with a plant stand reduced to 15,000 by cutworm injury, would be expected to yield 82 percent of a normal stand. If such a field were replanted on May 19 to establish 27,500 plants per acre, the expected yield would be 90 percent of normal. Whether or not it will pay to replant such a field will depend on whether the yield increase of eight percentage points would repay the replanting costs. In this example, if replanting is delayed until near the end of May, the yield increase to be gained from replanting disappears.

Although uniformity of stand cannot be measured easily, studies have indicated that reduced plant stands will yield better if plants are spaced uniformly than if there are large gaps in the row. As a general guideline, yields will be reduced an additional 5 percent if there are many gaps of 4 to 6 feet in the row and an additional 2 percent for gaps of 1 to 3 feet.

Table 2.06. Row Length Required to Equal 1/1,000 Acre

Row width	Row length
20″	26′1″
28″	18′8″
30″	17′5″
32″	16′4″
36″	14′6″
38″	13′9″
40″	13′1″

Weather stress in corn

Corn frequently encounters some weather-related problems during the growing season. The effect of such problems differs with the severity and duration of the stress and the stage of crop development at the time of the stress. Some of the possible stress conditions and their effects on corn growth and yield are:

A. **Flooding.** The major stress caused by flooding is simply a lack of oxygen needed for the proper function of the root system. When plants are very small, they will generally be killed after about five or six days of being submerged. Death will occur more quickly if the weather is hot, because high temperatures speed up the biochemical processes that use oxygen, and warm water has less dissolved oxygen. Cool weather, on the other hand, may allow plants to live for more than a week under flooded conditions. When plants reach the six- to eight-leaf stage, they can tolerate a week or more of standing water, though total submergence may increase disease incidence, and plants will suffer from reduced root growth and function for some days after the water recedes. Tolerance to flooding generally increases with age, but reduced root function due to lack of oxygen is probably more detrimental to yield before and during pollination than during rapid vegetative growth or during grainfill.

B. **Hail.** The most common damage from hail is loss of leaf area, though stalk breakage and bruising of the stalk and ear can be severe. Loss charts based on leaf removal studies generally confirm that defoliation at the time of tasseling causes the

greatest yield loss, while loss of leaf area during the first month after planting or when the crop is near maturity generally causes little yield loss. Loss of leaf area in small plants usually delays their development, however, and plants that experience hail may not always grow normally afterward.

C. **Cold injury.** Corn is of tropical origin and is not especially tolerant of cold weather. While the death of leaves from frost is the most obvious type of cold injury, leaves are damaged by temperatures below the low 40s, and photosynthesis can be reduced even if the only symptom is a slight loss of leaf color. The loss of leaves from frost is generally not serious when it happens to small plants, though such loss will delay plant development and could delay pollination to a less favorable (or, rarely, a more favorable) time. Frost injury symptoms may appear on leaves even when nighttime temperatures do not fall below the mid-30s; radiative heat loss can lower leaf temperatures to several degrees below air temperatures on a clear, calm night. If frost kills leaves before physiological maturity (black layer) in the fall, sugars can usually continue to move from the stalk into the ear for some time, although yields will generally be lowered, and harvest moisture may be high due to high grain moisture at the time of frost and slow drying rates that usually follow premature death.

D. **Drought.** Through the late vegetative stage (i.e., the end of June in normal years), corn is fairly tolerant of dry soils, and mild drought during June may even be beneficial, because roots generally grow downward more strongly as surface soils dry, and the crop benefits from the greater amount of sunlight that accompanies dry weather. During the two weeks before and two weeks following pollination, corn is very sensitive to drought, however, and dry soils during this period can cause serious yield losses. Most of these losses are due to failure of pollination, and the most common cause is the failure of silks to emerge from the end of the ear. When this happens, the silks do not receive pollen; thus the kernels are not fertilized and will not develop. Drought later in grainfill has a less serious effect on yield, though root function may decrease and kernels may not fill completely.

E. **Heat.** Because drought and heat usually occur together, many people assume that high temperatures are a serious problem for corn. In fact, corn is a crop of warm regions, and temperatures less than 100°F usually do not cause much injury *if soil moisture is adequate.* Extended periods of hot, dry winds can cause some tassel "blasting" and loss of pollen, but pollen shed usually takes place in the cooler hours of the morning, and conditions severe enough to cause this problem are unusual in Illinois. There is evidence that hybrids vary in their sensitivity to both heat and drought, though very tolerant hybrids usually give up some yield potential. As a result, they may not be good choices for average conditions.

Estimating yields

Making plans for storage and marketing of the corn crop often calls for estimating yields before the crop is harvested. Such estimations are easier to make for corn than for most other crops because the number of plants or ears per acre can be counted fairly accurately.

Estimating corn yields is done by counting the number of ears per acre and the number of kernels per ear, then multiplying these two numbers to get an estimate of the number of kernels per acre. Next, simply divide by an average number of kernels in a normal bushel to get the yield in bushels per acre.

Corn yields can be estimated after the kernel number is fixed — about 2 weeks after the end of pollination. The following steps are suggested:

1. Walk out in the field a predetermined number of rows and paces. For example, go 25 rows from the edge of the field and 85 paces from the end of the field. If this pattern is not determined beforehand, there will be a tendency to stop where the crop looks better than average. Stop *exactly* where planned.
2. Measure $\frac{1}{1,000}$ of an acre (Table 2.06), and count the number of *ears* (not stalks) in that distance. Do not count ears with only a few scattered kernels.
3. Take three ears from the row that was counted. To avoid taking only good ears, take the third, sixth, and tenth ears in the length of row. Do not take ears with so few kernels that they were not included in the ear count.
4. Count the number of rows of kernels and the number of kernels per row on each ear. Multiply these two numbers together for each ear, then average this kernel count for the three ears.
5. Calculate yield using the following formula:

$$\text{bu/acre} = \frac{\text{number of ears per } \frac{1}{1,000} \text{ acre} \times \text{average number of kernels per ear}}{90}$$

6. To get a reliable average, repeat this process at least once for every 5 acres in a field.

In the formula, the number 90 is used based on the assumption that a bushel of normal-sized seed contains about 90,000 kernels. The zeros are dropped because the plant population is given in thousands per acre. Table 2.07 gives estimated yields for different plant populations and kernel numbers.

Specialty types of corn

Erratic and generally low world corn prices have resulted in considerable interest among producers in

Table 2.07. Estimated Corn Yields for Different Ear Sizes and Plant Populations

Ears/acre '000s	Kernels/ear												
	400	450	500	550	600	650	700	750	800	850	900	950	1,000
	bushels per acre												
15	67	75	83	92	100	108	117	125	133	142	150	158	167
16	71	80	89	98	107	116	124	133	142	151	160	169	178
17	76	85	94	104	113	123	132	142	151	161	170	179	189
18	80	90	100	110	120	130	140	150	160	170	180	190	200
19	84	95	106	116	127	137	148	158	169	179	190	201	211
20	89	100	111	122	133	144	156	167	178	189	200	211	222
21	93	105	117	128	140	152	163	175	187	198	210	222	233
22	98	110	122	134	147	159	171	183	196	208	220	232	244
23	102	115	128	141	153	166	179	192	204	217	230	243	256
24	107	120	133	147	160	173	187	200	213	227	240	253	267
25	111	125	139	153	167	181	194	208	222	236	250	264	278
26	116	130	144	159	173	188	202	217	231	246	260	274	289
27	120	135	150	165	180	195	210	225	240	255	270	285	300
28	124	140	156	171	187	202	218	233	249	264	280	296	311
29	129	145	161	177	193	209	226	242	258	274	290	306	322
30	133	150	167	183	200	217	233	250	267	283	300	317	333
31	138	155	172	189	207	224	241	258	276	293	310	327	344
32	142	160	178	196	213	231	249	267	284	302	320	338	356

growing various specialty types of corn, either for export or for domestic use. This may mean higher profits if the supply of such types is quite small. Because the total demand might also be quite limited, however, the price advantage may disappear as more producers start growing a particular specialty type. It is therefore important to have other uses for the crop (for example, as livestock feed) and to grow types that do not yield substantially less than normal corn, in the event that the corn cannot be sold for its intended special use.

Many specialty types are grown under contract. The contract buyers often specify what hybrids may or may not be used, and they may specify other production practices to be used. Some contracts also may include pricing information and quality specifications.

Risks associated with growing specialty types of corn vary considerably. Milling companies may buy corn with "food-grade endosperm," requiring only that the grower choose hybrids from a relatively long list of popularly grown hybrids; the risk in this case is small. On the other hand, inbreds used to produce some hybrids are not very vigorous, and seed corn production with such inbreds might be very risky. Production contracts in such cases may shift some of the risk to the buyer. In any case, every grower of specialty types of corn should be aware of risks associated with each type.

White corn

Most of the white corn grown in the United States is used to make cornflakes, cornmeal, and grits. It often sells at a higher price than yellow corn, sometimes as much as double that of yellow corn.

The cultural practices for producing white corn are the same as those for yellow corn except that many of the white hybrids are quite late in maturity when grown in Illinois. Choice of hybrid is therefore important. In addition, kernels fertilized by pollen from yellow hybrids will be light yellow. These yellowish kernels are undesirable. The official standards for corn specify that white corn cannot contain more than 2 percent of corn of other colors; therefore, white corn probably should not be planted on land that produced yellow corn the year before. It may also be desirable to harvest the outside ten or twelve rows separately from the rest of the field. Most of the pollen from adjacent yellow corn will be trapped in those outer rows.

High-lysine corn

Normal dent corn is deficient in lysine, an amino acid needed in the diet of non-ruminant animals. In 1964 it was found that the level of this essential amino acid is controlled genetically and can be increased by incorporating a gene called *opaque-2* into corn. Feeding trials demonstrated that substantially less soybean meal was required when high-lysine corn was fed to swine.

Agronomic research with high-lysine corn indicates that it is slightly lower in yield and higher in moisture than its normal counterpart, and kernels may be softer and more susceptible to damage. Current research involving genes in addition to *opaque-2*, however, has successfully reduced some of these differences.

The *opaque-2* gene is recessive: High-lysine corn pollinated by normal pollen produces normal low-lysine grain. Production practices for high-lysine corn are similar to those for normal corn.

Popcorn

As with several of the other specialty types of corn, most of the popcorn produced in Illinois is under contract to processors. While there are several dozen hybrids from which to choose, the processor may require that a hybrid be grown for its particular kernel characteristics rather than for yield alone. Thus, income per acre should be considered because low-yielding hybrids may often bring a higher price.

Cultural practices for popcorn are much like those for field corn. Popcorn often is attacked by stalk rot; therefore, excessively high plant populations should be avoided, and harvest should begin as soon as the grain is dry enough. Weed control also may be more difficult because of slower emergence and early growth. Rotary hoeing and cultivation may be useful supplements to chemical weed control. Because popcorn yields 30 to 40 percent less than field corn, fertilizer needs should generally be somewhat lower.

Many newer popcorn hybrids are "dent sterile," meaning that field-corn pollen cannot fertilize popcorn kernels. This trait should reduce the need for isolation, but be sure to check with the contractor to verify this. Generally, it is best to avoid planting popcorn in a field where field corn grew the previous season.

High-oil corn

In the summer of 1896, C.G. Hopkins of the University of Illinois started breeding corn for high oil content. With the exception of 3 years during World War II, this research has continued. The oil content of the material that has been under continuous selection has been increased to 17.5 percent from the 4 to 5 percent that is normal for dent corn. Recent research involving new gene pools of high-oil material unrelated to the original Illinois High Oil indicates that varieties containing 7 to 8 percent oil may be produced with little or no sacrifice in yield. Higher-oil hybrids are now being marketed on a limited scale.

Because oil is higher in energy per pound than starch is, a livestock ration containing high-oil corn should have some advantage over one containing normal corn. There is also interest in high-oil corn as a source of edible oil. Corn oil has a high ratio of polyunsaturated fatty acids to saturated fatty acids. It is used in salad oils, margarine, and cooking oils.

Waxy maize

Waxy maize is a type of corn that contains 100 percent amylopectin starch instead of the 75 percent typical for ordinary dent hybrids. Amylopectin starch is used in many food and industrial products. Several corn-milling companies annually contract for its production in the central Corn Belt.

The waxy characteristic is controlled by a recessive gene, which means that waxy corn pollinated by pollen from normal corn will develop into normal dent corn. Waxy corn, like high-lysine corn, should not be planted in fields where dent corn is likely to volunteer. The outside six to ten rows may also need to be segregated from the rest of the field to keep the amount of contamination from normal corn at an acceptable level.

Normal dent corn hybrids can be converted to waxy hybrids by the relatively straightforward method of backcrossing, which introduces the waxy characteristic but leaves most of the agronomic traits intact. There are, therefore, a number of good waxy hybrids on the market, and their yields are often comparable to those of normal hybrids. The time required to complete the backcross process, however, will usually mean that the introduction of a waxy type lags a few years behind that of its normal parent hybrid.

High-amylose corn

In high-amylose corn, the amylose starch content has been increased to more than 50 percent. Normal corn contains 25 percent amylose starch and 75 percent amylopectin starch.

The amylose starch content also is controlled by a recessive gene; therefore, isolation of production fields is important, as is selecting production fields that were not planted in normal corn the previous year.

Genetic engineering in corn

People have for centuries selected crop plants that had favorable genes and gene combinations, thereby improving yield and other characteristics. Modern genetic engineering is a tool that assists the breeding process by allowing researchers — once they have identified the useful genes in almost any plant, animal, or microbe — to put such a gene directly into the cells of a corn plant. If this "gene insertion" can be done without harming the genetic makeup of an existing variety (and this is by no means certain), then the characteristic carried by the new gene can become available very quickly.

While the possibilities for new genes to be identified and put into corn through utilization of genetic engineering techniques are almost endless, the first commercial applications of this technology will focus on traits that are controlled by a single gene. The first genetically engineered trait to become available commercially in corn was resistance to certain classes of herbicide — imidazolinone resistant (IR) corn hybrids are now available. Corn hybrids containing the gene (from bacteria) to produce the insecticide known as *b.t.* are in the final stages of development. Other developments likely in the next few years include resistance to other herbicides, modified kernel characteristics, and resistance to some diseases for which genetic resistance has not been found in corn.

Though genetic engineering offers some very exciting possibilities for the introduction of traits controlled by one or two genes, sustained improvement in complex characteristics such as grain yield will, at least for now, depend on traditional breeding programs. Such improvement, while perhaps less dramatic than some of the genetic engineering developments, will continue to enable Illinois producers to maintain their comparative advantage in the production of corn.

Chapter 3.
Soybeans

Planting date

Soybeans generally yield best when planted in May, with full-season varieties tending to yield best when planted in early May. Earlier varieties, however, often yield more when planted in late May than in early May. When the planting of full-season varieties is delayed until late May, the loss in yield is minor compared with the penalty for planting corn late. Therefore, the practice of planting soybeans after corn has been planted is accepted and wise.

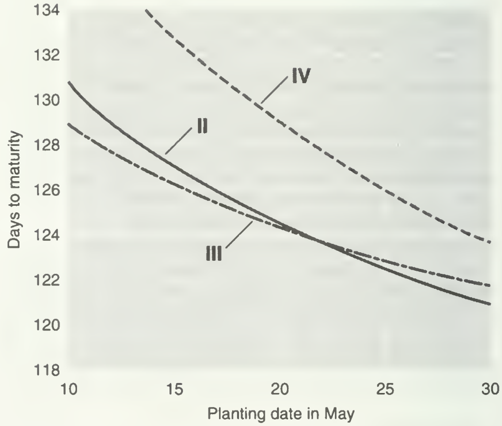
The loss in yield of soybeans becomes more severe when planting is delayed past early June. The penalty, however, for late-planted corn is proportionally greater, and the danger of wet or soft corn becomes such a threat that soybeans are, under most conditions, a better crop for late planting than corn.

Planting date has an effect upon the length of time it takes soybeans to mature. The vegetative stage (planting to the beginning of flowering) is 45 to 60 days for full-season varieties planted at the normal time. This period is shortened as planting is delayed and may be only about 25 days when these varieties are planted in late June or early July.

Soybeans are photoperiod responsive and the length of the night or dark period is the main factor that determines when flowering begins. Also, the vegetative period is influenced by temperatures — with high temperatures shortening and low temperatures lengthening it. But the main effect remains that of the length of the dark period.

As planting is delayed, the length of the flowering period and that of pod-filling also are shortened; but the effect of planting time on these periods is minor compared with that on the vegetative period.

As the length of the vegetative period grows shorter, because of delayed planting, soybean plants mature in fewer days (Figure 3.01).



Dates are average planting and maturity dates compiled from USDA Uniform Soybean Tests Northern States, 1980–1993.

Figure 3.01. Planting date effect on maturity of soybeans with Group II, III, and IV maturities.

Early planting

The practice of moving soybean planting to an earlier date (before early May) has been tried by some farmers in recent years. The success of such planting has not been consistent, and the merits of such planting dates can be questioned because added risks are associated with the cropping practice. The typically colder and wetter soil into which soybeans will be planted before early May will tend to provide an environment favorable to various pathogens.

Seed can be consumed by disease before soybean seedings are established. Additionally, low temperatures experienced by soybeans planted exceptionally early will simply delay germination activity by the

seed. Should the period prior to early May favor germination and emergence of soybeans, the plants are then at added risk due to late frosts of the season. Pathogens, low soil temperature, and added risk of frost injury can reduce stands achieved in the field, potentially lowering yield.

Research conducted at DeKalb and Monmouth evaluated the effect which seeding before and after early May would have on final soybean yield. With few exceptions, yields have not been enhanced with planting before early May. Similar results were obtained from an analogous study conducted in Iowa.

Figure 3.02 summarizes results of various soybean planting dates on soybean yield at DeKalb and Monmouth. The lack of an advantage for planting before April 25 at those locations is seen in the lines plotting yield obtained with such early planting.

Planting rate

Maximum yields for May and very early June plantings of soybeans generally are provided by planting rates that result in 8 to 10 plants per foot of row at harvest in 40-inch rows, 6 to 8 plants in 30-inch rows, 4 to 6 plants in 20-inch rows, or 3 to 4 plants in 10-inch rows. Higher populations will usually result in excessive lodging in all varieties except those that are extremely lodging resistant. With populations that are sufficiently low, yield may be lower because the plants fail to form a complete canopy, which fully utilizes available sunlight. Lower population densities also tend to branch more and pod lower, two factors that can lead to increased harvest losses and lower yields.

As row spacing narrows, fewer seeds per foot of row are needed to achieve a given rate of seeds per acre (Table 3.01). Remember that the plant population achieved is always less than the seeding rate used. Some seeds simply are not viable, while others fail to establish a plant because of disease, excessive planting depth, or other problems.

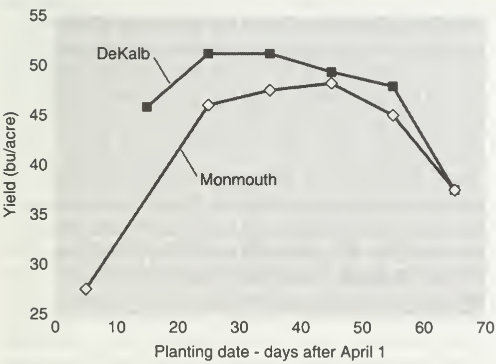


Figure 3.02. Seeding date effect on soybean yield, Monmouth and DeKalb.

Seeding-rate studies have demonstrated the productive capacity of soybeans at rather low plant densities. At extremely low plant densities, a considerable amount of the production may not be harvestable with a conventional combine because of low podding and excessive branching on the plant. Precipitation during vegetative development will help determine what the "ideal" plant density is for a given year. In a dry year, when vegetative development of plants is restricted, thicker stands of soybeans are desirable so that the smaller plants can develop a full crop canopy. In a year with considerable rain during May and June, which causes plants to grow taller and can lead to lodging by the crop, somewhat lower plant densities are better to avoid excessive lodging. At the time of planting, however, you cannot predict precipitation during vegetative growth, so a compromise in seeding rate offers the most potential.

Seeding-rate trials conducted on numerous varieties across several years suggest that a wide range of seeding rates will produce good yields. Seeding rates of 110,000 to 150,000 seeds per acre tend to produce the best yields (Figure 3.03). For seed of average size, these rates correspond to roughly 40 to 60 pounds per acre. Planting at rates toward the high end of this range helps ensure a full stand, while planting toward the low end of the range helps conserve seed. Virtually all soybean varieties respond to changes in seeding rate in a similar manner. Possible exceptions are varieties with weak stems (which lodge easily) and those with a determinate growth habit (which have reduced capacity to produce vegetative growth after the onset of flowering).

If seeding of soybeans is delayed until late June or early July, vegetative development of the plant will be greatly reduced. The smaller plants that develop will be resistant to lodging. The small stature of the plants limits the amount of sunlight each can intercept; to compensate for this effect, the seeding rate is increased. Increases of 50 to 100 percent over that suggested for May plantings are advisable.

Accurate calibration of planting equipment is needed to achieve stands desired in soybeans. When producers plant soybeans with grain drills, a guide provided by

Table 3.01. Soybean Plants/Foot of Row for Different Populations in Various Row Spacings

Row spacing (in.)	Soybean population (1,000s/acre)				
	125,000	150,000	175,000	200,000	225,000
	Average number of plants/foot of row required				
36″	8.6	10.3	12.0	13.8	15.5
30″	7.2	8.6	10.0	11.5	12.9
15″	3.6	4.3	5.0	5.7	6.5
10″	2.4	2.9	3.3	3.8	4.3
8″	1.9	2.3	2.7	3.1	3.4
7″	1.7	2.0	2.3	2.7	3.0

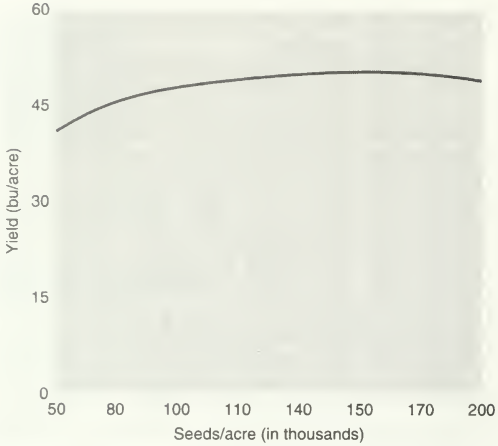


Figure 3.03. Effect of seeding rate on soybean yields.

the manufacturer is generally used to adjust seeding rate to a given number of pounds per acre. Since soybean seeds vary in size, due to both their variety and the environment in which they are produced, a pound per acre value appropriate for one variety may not be appropriate for another. With information on the number of seeds per pound in seed available for planting and a desired seed drop rate, Table 3.02 can aid in the calibration of seed drop rate when planting with a grain drill.

Planting depth

Emergence will be more rapid and stands will be more uniform if soybeans are planted only 1½ to 2 inches deep. Deeper planting often results in lower emergence and poor stands.

Varieties differ in their ability to emerge when planted more than 2 inches deep. The description of a variety may mention an "emergence score," which reflects the ability of the seedling hypocotyl to elongate

Table 3.02. Soybean Seeding Requirements for Different Seed Sizes and Seed Drop Rates

Seed per lb	Desired seed drop/acre 150,000	175,000	200,000	225,000
	pounds of seed to plant with a drill			
1,800	83	97	111	125
2,000	75	88	100	113
2,200	68	80	91	102
2,400	63	73	83	94
2,600	58	67	77	87
2,800	54	63	71	80
3,000	50	58	67	75
3,200	46	54	63	70

sufficiently when planting is deeper than recommended. Scores for emergence are usually given on a 1-to-5 scale, with a score of 1 indicating that the likelihood of emergence is very good and a score of 5 indicating that such probability is very weak. Special attention should be given to the planting depth of varieties that are known to have weaker emergence potentials. Because a variety has a tendency to emerge slowly or weakly from excessively deep planting does not mean it lacks the ability to produce a good crop when planted at a reasonable depth. It simply means that extra attention to depth of planting is needed to ensure a good stand.

Crop rotation

The crop preceding soybeans has an influence on yield potential. If soybeans are planted after soybeans, diseases and other pest problems may be intensified in the second and later years of production. Difficult-to-control weed problems will become worse. Research evidence also suggests that growth-inhibiting substances (allelopathic chemicals) are released from soybean residue as it decomposes in the soil. These substances have a negative effect on growth and production of soybeans. To avoid this problem, sufficient time must elapse between one soybean crop and the next to allow decomposition of the soybean crop residue. Planting soybeans after soybeans will not provide a sufficient interval.

Several studies on the rotation benefits for soybean yield have been done. Table 3.03 summarizes these results, which indicate that higher yields tend to result from soybeans grown in rotation, compared to those from soybeans after soybeans.

Row width

If weeds are controlled, soybeans often will yield more in narrow rows than in traditional row spacings of at least 30 inches. The yield advantage for narrow rows is usually greatest for earlier-maturing varieties, with full-season varieties showing smaller gains in yield as row spacing is reduced to less than 30 inches. A multiyear study illustrates that average gains for narrow versus wider row spacings will vary from year to year (Table 3.04).

The following rule of thumb predicts situations in which narrower row spacings will likely be advantageous to yield: If a full canopy of leaves is not developed over the ground by the time that pod development begins, narrower spacings for soybeans can be advantageous to yield.

In addition to row spacing, factors that influence canopy development by the time podding begins are (1) relative maturity of the variety grown, (2) growing conditions during the vegetative period of plant development, and (3) planting date. Varieties that mature

Table 3.03. Effect of Crop Rotation on Soybean Yields

Location	Soybeans after Soybeans	Soybeans after Corn
	bushels per acre	
DeKalb	39	44
Dixon	30	35
Urbana	44	50
Brownstown	30	35

relatively early generally have the smallest canopies when podding begins and, consequently, can benefit most from narrow-row spacings. Dry or otherwise undesirable weather early in the season will reduce the amount of canopy developed before the onset of flowering by the soybean. When such weather patterns occur, rows that are more narrow help develop a full canopy by the time podding begins. Delays in planting reduce the amount of canopy that develops before seed formation activity of the plant begins; thus when planting is delayed considerably, soybeans respond to narrower rows with yield increases. Double-crop soybeans planted after the small-grain harvest should be planted in rows no wider than 20 inches (Table 3.05).

For many years, some Illinois farmers have planted their soybeans with a grain drill. Interest in this planting method has increased to the point that about 40 percent of the soybean acres of Illinois are planted this way. The availability of improved herbicides has helped producers to expand the use of this planting method. If the weeds can be kept under control, the small-grain drill is a practical narrow-row planting device for soybeans. Research does not always show an advantage for the 7- or 8-inch rows over 15- or 20-inch spacings, but the drilled beans usually yield better than those planted in rows spaced at least 30 inches apart. A key factor to successful planting with a grain drill is good weed control. Also, with a grain drill, planting depth is more difficult to control. Because of these possible problems, farmers trying this planting method are wise to do so on a small acreage first.

For additional information about planting soybeans with a grain drill, see Illinois Cooperative Extension Service Circular 1161, *Narrow-Row Soybeans: What to Consider.*

When to replant

Uniform full stands have been compared to those with irregular deficiencies of varying magnitudes to evaluate yield potentials of stands that are less than perfect (Table 3.06 and Table 3.07). Studies strongly suggest that the soybean plant has a tremendous ability to compensate for missing plants. By developing more branches and podding more heavily, the effect of missing plants in the stand is often not detected in yields. Yield reduction that is suffered with very poor stands may still be more profitable to the grower than a replanted field, which has additional costs associated with replanting and a reduced yield potential because of a delayed seeding date.

Data in Table 3.06 illustrate the soybean's ability to compensate for missing plants when randomly placed gaps occur in the stand. The influence of plant density

Table 3.04. Average Yield of 30 Soybean Lines in Wide- and Narrow-Row Spacings, 1980-83

Year	Row spacings, inches			Narrow-row yield advantage
	30	15	10	
1980	39.8	41.4	...	4%
1981	55.8	...	61.6	10%
1982	56.1	...	57.9	3%
1983	53.5	...	54.4	2%

Table 3.05. Yield of Double-Crop Soybeans When Planted in 20- and 30-Inch Rows, 1972

Site	Row spacings, inches	
	20	30
Dixon Springs	53	43
Brownstown	37	32
Urbana	33	24

Table 3.06. Percent of Full-Yield Potential for Timely Planted Soybeans, as Influenced by Plants per Foot of Row and Percent Stand Reduction

Stand reduction	Plants per foot of row[a]		
	8	6	4
		percent of full-yield potential	
0 (full stand)	100	97	95
10 percent	98	96	93
20 percent	96	93	91
30 percent	93	90	88
40 percent	89	86	83
50 percent	84	81	78
60 percent	78	75	73

[a] Plants per foot of row in row sections with no gaps or skips.

Table 3.07. Percent of Full Yield Expected from Replanting Soybeans, As Influenced by Plants per Foot of Row and Stand Deficiency

Stand-deficiency level	Plants per foot of row[a]		
	8	6	4
		percent of full-yield potential	
0 (full stand)	89	86	83
10 percent	88	85	83
20 percent	86	84	81
30 percent	84	81	79
40 percent	81	78	75
50 percent	76	74	71
60 percent	71	69	66

[a] Plants per foot of row in row sections with no gaps or skips.

in the remaining row sections is also apparent from the table. For soybeans to exhibit their full capacity to compensate for missing plants, it is necessary to control weed growth in the areas without soybean plants. In a field situation where poor stands are realized, management to control weeds is essential to prevent further yield losses due to the poor stand. The cost of maintaining the necessary weed control must be considered a cost of keeping a less-than-perfect stand.

Growers who replant do so at a later planting date than is the optimum. A penalty to yield due to delayed planting of 2 to 3 weeks is reflected in values presented in Table 3.07. The plant density per foot of row achieved with replanting, along with possible gaps in that stand, will also influence yield potential. It is wise to remember that replanted soybeans are not guaranteed to grow: A perfect stand is not always achieved when a poor stand is destroyed and the field replanted.

At a given level of stand reduction, the impact on yield is minimized if the gaps are small rather than large in size. A gap size of 16 inches has been found to have no influence on yield of soybeans grown in 30-inch row spacing, provided adjacent rows have a full stand. Compensation for gaps in the row has been found to occur not only in the row where the gap is located but also in the rows bordering the gap. The degree of compensation exhibited by soybeans should be enhanced as rows are spaced closer together, for under such planting arrangements the plants are initially more uniformly spaced in the field, making it more likely they can fully compensate for a stand deficiency of a given level. Extension Circular 1317, *Managing Deficient Soybean Stands,* can be useful to growers making a replanting decision.

Double-cropping

See Illinois Cooperative Extension Circular 1106, *Double-Cropping in Illinois.*

Seed source

To ensure a good crop, you must do a good job of selecting seed. When evaluating seed quality, consider the percent germination, percent pure seed, percent inert matter, percent weed seed, and the presence of diseased and damaged seed.

Samples of soybean seed taken from the planter box as farmers were planting showed that homegrown seed was inferior to seed from other sources (Table 3.08). The number of seeds that germinate and the pure seed content of homegrown seeds were lower. Weed seed content, percent inert material (hulls, straw, dirt, and stones), and presence of other crop seeds (particularly corn) in homegrown seed were higher.

This evidence indicates that the Illinois farmer can improve soybean production potential by using higher-quality seed. Homegrown seed is the basic problem.

Table 3.08. Quality Differences in Soybeans from Different Sources

Source	Germination, %	Pure seed, %	Inert matter, %	Seed cleaned, %	Seed germination tested, %
1985 survey					
Certified seed .	88.2	99.5	0.42	100	100
Bin-run seed . .	85.9	98.1	1.19	51	14
1986 survey					
Certified seed .	89.0	99.4	0.29	100	100
Bin-run seed . .	87.7	98.6	1.59	90	10

Few producers are equipped to carefully harvest, dry, store, and clean seeds, and to perform laboratory tests that adequately assure high-quality seed. A grower who is not a professional seed producer and processor may be well advised to market the homegrown soybeans and obtain high-quality seed from a reputable professional dealer.

A state seed tag is attached to each legal sale from a seed dealer. Read the analysis and evaluate if the seed being purchased has the desired germination, purity of seed, and freedom from weeds, inert material, and other crop seeds. The certification tag verifies that an unbiased nonprofit organization (in our state, the Illinois Crop Improvement Association) has inspected the production field and the processing plant. These inspections make certain that the seeds are of a particular variety as named and have met certain minimum quality standards. Because some seed dealers may have higher quality seed than others, it always pays to read the tag.

Seed size

The issue of how the size of seed planted affects soybean growth and the final yield often arises following a year with stress during the seed-fill period, which reduces final seed size. Research suggests little detrimental effect from planting seed that is smaller than normal.

Across a broad range of seed sizes, insignificant effects on emergence have been reported. Seeds of extremely small size, which normally do not make their way into the seed market, may be reduced in emergence when planted at a normal seeding depth of 1 to 2 inches.

Final differences in plant size, which might result from planting seeds of different sizes, do not suggest any problems with using small seed. Any differences reported on final plant size are so small (less than 4 inches) that they would likely not have a significant effect on yield.

The size of seed produced by soybeans is determined by a combination of genetic factors for the variety and the environment in which the seeds develop. Whether soybeans are large or small, seed for a given variety has the same genetic potential. Therefore, the size of

the seed produced on a plant established by planting a small seed will be expected to be the same as the size of the seed from a plant grown from large seed.

Effects of the seed size on final yield, which is the ultimate concern of growers, appears to be minimal. When shopping for soybean seed, seed quality should be a more important consideration than actual seed size. If smaller-than-normal seed will be used to establish soybeans, check your planter calibration to meter the seed at the proper rate. Excessive seeding rates, resulting from misadjusted planting equipment metering small seed, can result in excessively thick stands that will be more prone to lodging.

Varieties

Soybean varieties are divided into maturity groups according to their relative time of maturity (see Table 3.09, Table 3.10, and Table 3.11). Varieties of Maturity Group I are nearly full season in northernmost Illinois but are too early for good growth and yield farther south. In extreme southern Illinois, varieties in Maturity Groups IV and V are best adapted.

Traditionally, soybeans grown in the Midwest have had indeterminate growth habits; that is, vegetative growth continues beyond the time when flowering begins, continuing generally until seed filling begins. In recent years, a few varieties with determinate growth habits have been developed and released in the Midwest. The main reason for their introduction was to provide varieties that are highly resistant to lodging, which would be most useful in environments where lodging is a yield-limiting factor. Determinate growth habit, which is a genetically controlled trait, stops vegetative growth on the main stem when flowering begins; this produces a relatively short plant that is quite resistant to lodging. With this growth pattern, determinate soybeans must develop adequate leaf material before flowering.

Table 3.09. Morphologic Characteristics of Soybean Varieties

Maturity group and variety	Flower color	Pubescence color	Pod color	Seed luster	Hilum color
I					
Archer	purple	gray	tan	dull	imblk[a]
Bell	purple	tawny	tan	shiny	black
BSR 101	purple	gray	tan	intermediate	imblk[a]
II					
Burlison	white	tawny	tan	dull	black
Chapman	purple	gray	brown	shiny	imblk[a]
Conrad	purple	tawny	tan	dull	brown
Conrad 94	purple	tawny	tan	dull	brown
Corsoy 79	purple	gray	brown	dull	yellow
Hack	white	gray	tan	shiny	buff
IA3003	purple	tawny	brown	shiny	black
Jack	white	gray	brown	dull	yellow
Kenwood 94	purple	tawny	brown	dull	black
III					
Cartter	white	tawny	tan	shiny	black
Chamberlain	purple	tawny	brown	shiny	black
Edison	purple	tawny	tan	shiny	black
Fayette	white	tawny	tan	shiny	black
Hobbit 87	white	tawny	tan	shiny	black
Kunitz	white	brown	tan	shiny	black
Linford	white	tawny	tan	shiny	black
Pella 86	purple	tawny	tan	dull	black
Piatt	white	gray	tan	dull	buff
Probst	purple	tawny	tan	shiny	black
Resnik	purple	tawny	tan	dull	black
Saline	white	gray	tan	dull	buff
Sherman	white	gray	brown	shiny	buff
Williams 82	white	tawny	tan	shiny	black
Yale	white	gray	tan	dull	buff
IV					
Bronson	white	tawny	tan	indeterminate	black
Delsoy 4210	white	tawny	tan	shiny	gray
Delsoy 4710	purple	tawny	tan	intermediate	black
Flyer	purple	tawny	tan	dull	black
Hamilton	white	gray	brown	shiny	buff
KS4694	white	gray	brown	dull	buff
Nile	white	tawny	tan	shiny	black
Pharaoh	purple	tawny	tan	shiny	brown
Spry	purple	tawny	brown	dull	black
Union	white	tawny	tan	shiny	black
V					
Essex	purple	gray	tan	intermediate	buff

[a] Imperfect black hilum.

Table 3.10 Reactions of Soybean Varieties to Phytophthora Root Rot Disease

Maturity group	Susceptible to Phytophthora root rot	Resistant to races 1 and 2	Resistant to races 1, 2, and others
I	Bell	BSR 101	Archer
II	Conrad Jack	Hack	Burlison Chapman Corsoy 79 Kenwood 94 Conrad 94
III	Cartter Fayette IA3003 Linford Saline Sherman Yale	Chamberlain Piatt	Edison Hobbitt 87 Kunitz Pella 86 Probst Resnik Thorne Williams 82
IV	Delsoy 4210 Delsoy 4710 Hamilton KS4694 Nile Pharaoh Spry	Bronson Union	Flyer
V	Essex		

Table 3.11. Soybean Variety Characteristics

Maturity group and variety	Protected variety[a]	Relative maturity[b]	Lodging	Height	Soybean cyst nematode[c]	
		days	*score*[d]	*inches*	*race 3*	*race 4*
II						
Burlison	Yes	−8	1.9	35	S	S
Chapman	Yes	−8	2.0	36	S	S
Conrad 94	No	−11	1.8	35	S	S
Jack	Yes	−1	2.7	44	R	R
Kenwood 94	No	−6	2.3	36	S	S
III						
Chamberlain	Yes	+4	2.4	40	S	S
Edison	Yes	+2	1.6	35	S	S
Hobbit 87	Yes	+6	1.0	21	S	S
IA3003	No	−5	2.0	33	S	S
Linford	No	+4	2.7	41	R	R
Piatt	Yes	+4	2.7	41	S	S
Probst	Yes	+2	1.9	37	S	S
Resnik	Yes	9/16	1.7	34	S	S
Salikne	Yes	+4	2.2	39	R	R
Thorne	Yes	+3	1.9	34	S	S
Williams 82	No	+3	2.1	39	S	S
Yale	No	+2	1.7	36	R	R
IV						
Bronson	Yes	+10	2.5	44	R	R
Delsoy 4210	Yes	+6	2.7	43	R	R
Delsoy 4710	Yes	+10	3.3	44	R	R
Flyer	Yes	+5	1.8	37	S	S
Hamilton	Yes	+5	2.5	36	S	S
KS4694	Yes	+11	1.7	34	S	S
Nile	No	+9	2.5	42	R	S
Spry	Yes	+12	2.1	32	S	S

[a] U.S. Protected Variety; see the chapter titled "Seed Production."
[b] Relative to Resnik.
[c] R = resistant; S = susceptible.
[d] 1 = all plants standing; 5 = all plants flat.

While determinate varieties can be very productive in a favorable environment, they can also disappoint growers when production is attempted in a low-yield environment. Determinate varieties will be most useful and profitable to growers in environments where conditions favor rapid early-season vegetative growth, the same conditions that can possibly lead to lodging problems with indeterminate varieties. Lacking such an environment for soybean production, growers would be wise to use only indeterminate varieties.

The following is a list of public varieties of soybeans that are available in Illinois. If a variety is determinate, the description so notes — all others are indeterminate.

Maturity Group I

Archer provides resistance to brown stem rot and multiple races of Phytophthora root rot in Group I maturity. In addition, it has good lodging resistance.

BSR 101 has more genetic resistance to brown stem rot than does any other public variety in its maturity group. In addition, it has resistance to Phytophthora root rot, race 1. BSR 101 has more lodging resistance and better yield potential than Hardin, which has similar maturity.

Bell has a late Group I maturity which offers good yield potential along with resistance to races 3 and 4 of the soybean cyst nematode. It does not have resistance to Phytophthora.

Maturity Group II

Burlison has quite good yield potential for northern and central Illinois producers. It carries multiple race resistance to Phytophthora root rot, but is very sensitive to metribuzin herbicide. Maturity is toward the late side of Group II varieties.

Chapman has Group II maturity that combines multirace resistance to Phytophthora with improved yield potential.

Conrad has early Group II maturity which offers improved yield potential if Phytophthora and brown stem rot are not a problem. Because of susceptibility to these disease problems, growers should consider likely disease problems.

Conrad 94 is essentially an improved Conrad. Excellent resistance to Phytophthora root rot allows for improved yield over Conrad in many environments. It will be available to growers for the first time in the 1996 crop year.

Corsoy 79 is an improved version of Corsoy, similar to the original, with strong emergence and early Group II maturity. Like the original Corsoy, the Corsoy 79 has poor lodging resistance. Unlike the older Corsoy, however, it has resistance to seven races of Phytophthora root rot.

Hack has high yield potential and lodging resistance superior to other varieties of similar maturity. It has resistance to Phytophthora root rot, races 1 and 2, and to bacterial pustule.

IA3003 was selected from the cross Chamberlain X Conrad. It is resistant to brown stem rot, but is susceptible to Phytophthora root rot. It will be available for the first time in the 1996 crop year.

Jack will provide resistance to races 3 and 4 of the soybean cyst nematode with good yield potential in areas where a late Group II variety is adapted. It has moderate resistance to lodging and is susceptible to Phytophthora and brown stem rot disease.

Kenwoood 94 is essentially an improved Kenwood. Excellent resistance to Phytophthora root rot allows for improved yield. It will be available to growers for the first time in the 1996 crop year.

Maturity Group III

Cartter has a relatively early Group III maturity that offers growers resistance to soybean cyst nematode races 3 and 4, but it lacks resistance to Phytophthora root rot. It was developed from the same breeding program that produced Fayette.

Chamberlain has a mid-Group III maturity and resistance to brown stem rot disease. It also has resistance to bacterial pustule and races 1 and 2 of Phytophthora root rot. It has good resistance to lodging and has good yield potential.

Edison has an early Group III maturity, which offers improved yield along with multirace resistance to Phytophthora root rot.

Fayette is most useful to growers needing resistance to soybean cyst nematode, races 3 and 4. It matures about the same time as Williams 82. Fayette is susceptible to Phytophthora root rot and is moderately resistant to lodging. In the absence of cyst nematode problems, growers should not use Fayette, for other varieties of similar maturity yield better.

Hobbit 87 is an improved version of Hobbit. Resistance to Phytophthora equal to that found in Williams 82 is the notable improvement in this variety. Determinate growth, short stature, lodging resistance, and good yield potential of the original Hobbit are found in Hobbit 87.

Kunitz has a Group III maturity with multirace resistance to Phytophthora root rot. It is closely related and similar to Williams 82. It differs from other varieties in that it lacks the Kunitz trypsin inhibitor, which allows it to be used for on-farm feeding to swine during finishing stages of growth.

Linford maturity is toward the late side of Group III varieties. It offers resistance to races 3 and 4 of soybean cyst nematode, good lodging resistance and good yield potential. It lacks resistance to Phytophthora and brown stem rot, however.

Pella 86 is an improved version of Pella. It is a relatively early Group III variety with good lodging resistance and other characteristics of Pella. The improvement in Pella 86 is in Phytophthora resistance, which is equal to that of Williams 82.

Piatt offers improved yield potential in a maturity slightly later than Resnik. It has a determinate growth habit, but has a plant height similar to indeterminate types of similar maturity. It has some resistance to Phytophthora root rot. Seed size is rather small.

Probst has excellent resistance to Phytophthora root rot. It was selected from the cross Spencer X Resnik, has strong emergence, and has mid-Group III maturity. It will be available to producers for the first time in 1996.

Resnik is a mid-Group III variety, with good yield potential, lodging resistance, and Phytophthora resistance equal to that of Williams 82.

Saline matures approximately a week later than Resnik and has resistance to races 3 and 4 of soybean cyst nematode. Compared to Linford, it has improved yield, reduced lodging, and is a smaller seed. It is susceptible to Phythophthora root rot.

Sherman offers growers an improved yield potential in a variety that matures 2 or 3 days later than Pella. Although Sherman does not have genetic resistance to Phytophthora root rot, it offers yield advantages in environments where that disease is not a problem.

Thorne matures about a day later than Resnik, is resistant to Phytophthora root rot, and offers improved yield potential. It is rated moderately resistant to brown stem rot.

Yale has improved yield potential with resistance to races 3 and 4 of SCN. Compared to Linford, maturity is a day earlier, and lodging is less of a problem. In 1996 it will first be available to producers.

Williams 82 is an improved version of the Williams variety, which was released in the 1970s. It has a late Group III maturity. The Williams 82 has a broad base of resistance to Phytophthora root rot (races 1 to 10, 13 to 15, 17, 18, 21, and 22), allowing it to produce well across a wide range of root-rot infested fields. Plant size and yield potential are the same as in the original Williams variety.

Maturity Group IV

Bronson is resistant to races 3 and 4 of soybean cyst nematode. Maturity is mid-Group IV. Plants are tall, but have good resistance to lodging.

Delsoy 4210 has an early to mid-Group IV maturity and offers protection to soybean cyst nematode races 3 and 4. In addition to good yield potential, it stands well.

Delsoy 4710 has a late Group IV maturity and carries resistance to soybean cyst nematode races 3 and 4. Although it has improved yield, it tends to have a lodging problem in most environments as the plant grows tall.

Flyer offers producers excellent resistance to Phytophthora in a relatively early Group IV maturity. Resistance to lodging is quite good. Producers using Union may find Flyer better yielding.

Hamilton is an early Group IV with maturity equal to Union. It resists lodging better than Union and has higher yield potential, but lacks resistance to Phytophthora.

KS4694 has a late Group IV maturity, with yield

potential better than Flyer and Spencer. Growth is tall, but lodging resistance is good.

Nile carries resistance to race 3 of soybean cyst nematode in an early Group IV maturity. It offers growers good lodging resistance and improved yield potential.

Pharaoh is a fairly late Group IV with resistance to race 3 of soybean cyst nematode. If race 4 of soybean cyst nematode is a production problem, this variety may not be a good choice. Yield potential in its maturity range appears very good.

Spry is a late Group IV with exceptionally vigorous vegetative growth. It has determinate growth and somewhat shorter plant stature than other varieties of similar maturity. It has excellent resistance to lodging as well.

Union has resistance to Phytophthora, downy mildew, and bacterial pustule. Maturity is early in the Group IV maturity range. Lodging of Union has been a problem in environments that favor abundant vegetative development.

Maturity Group V

Essex has relatively early Group V maturity and is susceptible to soybean cyst nematode. It is resistant, however, to bacterial pustule, downy mildew, and frogeye leaf spot and has field tolerance to Phytophthora root rot. It has very good resistance to lodging.

Private varieties

Well over 500 varieties and brands of soybeans are available to Illinois growers. Each year the University of Illinois conducts the Commercial Soybean Performance Trials at numerous locations in the state. Each year a report on results of the soybean trials is published and is available from county Extension offices. In addition to yield, other information on maturity, lodging resistance, height, and shatter ratings is provided in the report.

Chapter 4.

Small Grains

Winter wheat

Although both soft red and hard red winter wheat can be grown in Illinois, improved soft wheat varieties are widely adapted in the state; nearly all of Illinois wheat is the soft type. The primary reasons for this are the better yields of soft wheat and the sometimes poor quality of hard wheat produced in our warm and humid climate. It may be difficult to find a market for hard wheat in many parts of the state; therefore, it is advisable to line up a market before planting the crop.

Wheat in the cropping system

In recent years, wheat acreage in Illinois has averaged about 1.5 million acres planted, with an average of about 1.3 million acres harvested. Most of the wheat acreage is in the southern half of the state, and a majority of the acreage south of I-70 is doublecropped with soybeans each year. Much of the crop in the northern part of the state is produced by livestock producers, who often value the straw as much as the grain, and who often spread manure on the fields after wheat harvest. For those considering producing wheat, the following points may help in making the decision:

1. State average yields have ranged from 32 to 59 bushels per acre over the past 15 years, with county average yields often correlated with average corn yields. Under very favorable spring weather conditions (i.e., with dry weather in May and June), yields on some farms have exceeded 100 bushels per acre. As a general rule of thumb, wheat yields will average about one-third those of corn, but will be about one-half those of corn when weather is favorable for both crops. With different weather requirements than corn and soybeans, wheat helps spread weather risks.
2. Wheat costs less to produce than corn, but gross and net incomes from the crop are likely to be less than for corn or soybeans. Added income from double-crop soybeans or from straw, however, improves the economic return from wheat. Wheat also provides income in mid-summer, several months before corn and soybean income.
3. Wheat is one of the best annual crops in Illinois for erosion control. This is due to the fact that it is in the field for some nine months of the year, and is well-established during heavy spring rainfall. Wheat can also serve as a crop to break rotations that would otherwise lead to buildups in disease or insects.
4. Wheat crop abandonment is higher than for other crops, but wheat acres not harvested can be planted to spring-seeded crops, usually at their optimum planting time.

Date of seeding

The Hessian fly-free dates for each county in Illinois are given in Table 4.01. Wheat planted on or after the fly-free date is much less likely to be damaged by the insect than wheat planted earlier. Wheat planted on or after the fly-free date also will be less severely damaged in the fall by diseases such as Septoria leaf spot, which is favored by the excessive fall growth usually associated with early planting. Because the aphids that carry the barley yellow dwarf (BYD) virus and the mites that carry the wheat streak mosaic virus are killed by freezing temperatures, the effects of these viruses will be less severe if wheat is planted shortly before the first killing freeze. Finally, wheat planted on or after the fly-free date will probably suffer less from soil-borne mosaic; most varieties of soft red winter wheat carry good resistance but may show symptoms if severely infested.

The decreases in yield as planting is delayed past the fly-free date vary considerably, depending on the year and location within Illinois. In general, studies have shown that yields decline only slowly with

Table 4.01. Hessian Fly-Free Date for Seeding Wheat

County	Average date of seeding wheat for highest yield	County	Average date of seeding wheat for highest yield	County	Average date of seeding wheat for highest yield	County	Average date of seeding wheat for highest yield
Adams	Sept. 30-Oct. 3	Ford	Sept. 23-29	Livingston	Sept. 23-25	Randolph	Oct. 9-11
Alexander	Oct. 12	Franklin	Oct. 10-12	Logan	Sept. 29-Oct. 3	Richland	Oct. 8-10
Bond	Oct. 7-9	Fulton	Sept. 27-30	Macon	Oct. 1-3	Rock Island	Sept. 20-22
Boone	Sept. 17-19	Gallatin	Oct. 11-12	Macoupin	Oct. 4-7	St. Clair	Oct. 9-11
Brown	Sept. 30-Oct. 2	Greene	Oct. 4-7	Madison	Oct. 7-9	Saline	Oct. 11-12
Bureau	Sept. 21-24	Grundy	Sept. 22-24	Marion	Oct. 8-10	Sangamon	Oct. 1-5
Calhoun	Oct. 4-8	Hamilton	Oct. 10-11	Marshall-Putnam	Sept. 23-26	Schuyler	Sept. 29-Oct. 1
Carroll	Sept. 19-21	Hancock	Sept. 27-30			Scott	Oct. 2-4
Cass	Sept. 30-Oct. 2	Hardin	Oct. 11-12	Mason	Sept. 29-Oct. 1	Shelby	Oct. 3-5
Champaign	Sept. 29-Oct. 2	Henderson	Sept. 23-28	Massac	Oct. 11-12	Stark	Sept. 23-25
Christian	Oct. 2-4	Henry	Sept. 21-23	McDonough	Sept. 29-Oct. 1	Stephenson	Sept. 17-20
Clark	Oct. 4-6	Iroquois	Sept. 24-29	McHenry	Sept. 17-20	Tazewell	Sept. 27-Oct. 1
Clay	Oct. 7-10	Jackson	Oct. 11-12	McLean	Sept. 27-Oct. 1	Union	Oct. 11-12
Clinton	Oct. 8-10	Jasper	Oct. 6-8	Menard	Sept. 30-Oct. 2	Vermilion	Sept. 28-Oct. 2
Coles	Oct. 3-5	Jefferson	Oct. 9-11	Mercer	Sept. 22-25	Wabash	Oct. 9-11
Cook	Sept. 19-22	Jersey	Oct. 6-8	Monroe	Oct. 9-11	Warren	Sept. 23-27
Crawford	Oct. 6-8	Jo Daviess	Sept. 17-20	Montgomery	Oct. 4-7	Washington	Oct. 9-11
Cumberland	Oct. 4-5	Johnson	Oct. 10-12	Morgan	Oct. 2-4	Wayne	Oct. 9-11
DeKalb	Sept. 19-21	Kane	Sept. 19-21	Moultrie	Oct. 2-4	White	Oct. 9-11
DeWitt	Sept. 29-Oct. 1	Kankakee	Sept. 22-25	Ogle	Sept. 19-21	Whiteside	Sept. 20-22
Douglas	Oct. 2-3	Kendall	Sept. 20-22	Peoria	Sept. 23-28	Will	Sept. 21-24
DuPage	Sept. 19-21	Knox	Sept. 23-27	Perry	Oct. 10-11	Williamson	Oct. 11-12
Edgar	Oct. 2-4	Lake	Sept. 17-20	Piatt	Sept. 29-Oct. 2	Winnebago	Sept. 17-20
Edwards	Oct. 9-10	LaSalle	Sept. 19-24	Pike	Oct. 2-4	Woodford	Sept. 26-28
Effingham	Oct. 5-8	Lawrence	Oct. 8-10	Pope	Oct. 11-12		
Fayette	Oct. 4-8	Lee	Sept. 19-21	Pulaski	Oct. 11-12		

planting delays for the first 10 days after the fly-free date. From 10 to 20 days late, yields decline at the rate of a bushel or so per day. This yield loss accelerates to as much as 2 bushels per day from 20 to 30 days late, with sharper declines in the northern part of the state than in southern Illinois. By one month after the fly-free date, yield potential is probably only 60 to 70 percent of normal, making this about the latest practical date to plant wheat and still expect a reasonable yield. Wheat may survive even if planted so late that it fails to emerge in the fall, but reduced tillering and marginal winterhardiness will often result in large yield decreases.

Rate of seeding

While seeding rate recommendations for wheat have usually been expressed as pounds of seed per acre, differences in seed size can mean that the number of seeds per acre or per square foot may not be very precisely specified. Recent research in Illinois has measured yield in response to varying the number of seeds from 24 to 48 seeds per square foot. Results are given in Table 4.02.

The results in Table 4.02 indicate that seed rates within this range affect yield very little, though in northern Illinois, where there was some cold injury in the spring, the extra plants gave a slight yield advantage. On average, though, it appears that a seeding rate of about 30 seeds per square foot is adequate for top yields.

Seed size in wheat varies by variety and by weather during seed production but is usually in the range of 13,000 to 17,000 seeds per pound. Table 4.03 gives the number of seeds per acre and the number of seeds per foot of row needed to plant different numbers of seeds per square foot. These numbers are useful for calibrating a drill. Some seed bags list the number of seeds per pound. If not, a simple estimate may be needed. Use the size range given above: large seed will have 12,000 to 13,000 per pound; medium about 15,000 per pound; and small seed about 17,000 to 18,000 per pound. At 15,000 seeds per pound, a

Table 4.02. Effect of Seed Rate on Wheat Yield

Seeds per square foot	Southern Illinois[a]	Northern Illinois[b]
	bushels per acre	
24	77.2	71.8
36	77.6	74.0
48	77.8	75.9

[a] Average of 4 trials conducted at Belleville and Brownstown.
[b] Average of 4 trials conducted at Urbana and DeKalb.

Table 4.03. Conversion Chart for Number of Small Grain Seeds or Plants Per Square Foot, Per Acre, and Per Linear Foot of Drilled Row

Seeds or plants per square foot	Seeds or plants per acre (millions)	Seeds or plants per foot of row at row spacing:			
		6 in.	7 in.	8 in.	10 in.
20	0.87	10	12	13	17
24	1.05	12	14	16	20
28	1.22	14	16	19	23
32	1.39	16	19	21	27
36	1.57	18	21	24	30
40	1.74	20	23	27	33

seeding rate of 1½ bushels per acre provides about 31 seeds per square foot. A stand of 25 to 30 plants per square foot is generally considered the optimum, and a minimum of 15 to 20 plants per square foot is needed to justify keeping a field in the spring.

If planting is delayed much past the fly-free date, then fall growth and spring tillering are likely to be reduced. To compensate, it is suggested that seeding rate be increased by one-half bushel if planting is 2 to 3 weeks after the fly-free date and by one bushel if planting is delayed by more than 3 weeks.

Seed treatment

Treating wheat seeds with the proper fungicide or mixture of fungicides is a cheap way to help ensure improved stands and better seed quality. Under conditions that favor the development of seedling diseases, the yield from treated seed usually will be 3 to 5 bushels higher than that from untreated seed.

The Department of Plant Pathology suggests that carboxin (Vitavax) or a combination of carboxin with captan, maneb, or thiram be used to treat wheat seed. Vitavax controls loose smut in wheat and barley and should be used if this disease was present in the field where the seed was produced. Because Vitavax is not effective on some other seed-borne diseases that cause seedling blight (such as Septoria), another fungicide should be used along with Vitavax. Should additional information about wheat diseases or seed treatment methods and materials be desired, contact the University of Illinois Department of Plant Pathology or the local Extension office. (See Chapter 18, Disease Management for Field Crops.)

Seedbed preparation

Wheat requires good seed-soil contact and moderate soil moisture for germination and emergence. Generally, one or two trips with a disk harrow or field cultivator will produce an adequate seedbed if the soil is not too wet. It is better to wait until the soil dries adequately before preparing it for wheat, even if planting is delayed.

No-till drills may be used for wheat, but the soil must be reasonably dry. Do not reduce seeding rates for no-till. It is also important that crop residue be spread uniformly before no-tilling wheat. Heavy residue cover may cause disease, nutrient, and winter survival problems. Fertilizer materials may be placed on the surface; the drilling action will incorporate them adequately for wheat.

Depth of seeding

Wheat should not be planted more than 1 to 1½ inches deep. Deeper planting may result in poor emergence, particularly with semidwarf varieties because coleoptile length is positively correlated with plant height. Drilling is the best way to ensure proper depth of placement.

Though a drill is best for placing seed at the right depth, a number of growers use a fertilizer spreader to seed wheat. This practice is somewhat risky but often works well, especially if rain falls after planting. The air-flow fertilizer spreaders will usually give a better distribution than the spinner type. If seed is broadcast, the seeding rate should be increased to 2 to 3 bushels per acre to compensate for uneven placement. After broadcast seeding, the field may be rolled with a cultipacker or cultimulcher (with the tines set shallow), or it may be tilled very lightly with a disk or tine harrow to improve seed-soil contact.

Row spacing

Research on row spacing generally shows little advantage for planting wheat in rows that are more narrow than 7 or 8 inches. Yield is usually reduced by wider rows, with a reduction of about 1 to 2 bushels in 10-inch rows. Wisconsin data show greater yield reductions in 10-inch rows, probably due to slower early growth than is common in Illinois.

Varieties

The genetic improvement of wheat has continued with the involvement of both the private sector and public institutions. As a result, there are now some 50 varieties sold in Illinois, with over half of this number provided by private companies.

Both public and private varieties are tested at six locations in Illinois each year, and the results are assembled in a report titled *Wheat Performance in Illinois Trials.* This report also contains descriptions of varieties, including both agronomic characteristics and resistance to diseases. Copies of this report are available in Extension offices by mid-August, thus allowing the use of this information before planting.

Intensive management

Close examination of the methods used to produce very high wheat yields in Europe has increased interest in application of similar "intensive" management practices in the United States. Such practices generally include narrow row spacing (4 to 5 inches); high seeding rates (3 to 4 bushels per acre); high nitrogen rates, split into three or more applications; and heavy use of foliar fungicides for disease control and plant growth regulators to reduce height and lodging.

From research conducted in Illinois, it has become apparent that responses to these inputs are much less predictable in Illinois than in Europe, primarily because of the very different climatic conditions. Following is a summary of research findings to date:

1. Research in Indiana and other states shows that the response to rows narrower than 7 or 8 inches is quite erratic, with little evidence to suggest that the narrow rows will pay added equipment costs.
2. Seeding rates of around 1½ bushels per acre (30

to 35 seeds per square foot) generally produce maximum yields.
3. Increasing nitrogen rates beyond the recommended rates of 50 to 110 pounds per acre has not increased yields. Splitting the spring nitrogen into two or more applications has not increased yields in most cases, but may do so if very wet weather after N application results in loss of N.
4. Although foliar fungicides are useful if diseases are found, routine use has resulted in yield increases of only 3 to 5 bushels per acre (Table 4.04) and is probably not economically justified.
5. The response to the plant growth regulator Cerone, which is labeled for use on wheat, has not been consistent. While there has been an occasional yield increase from the use of this chemical, especially where the yield levels were above 80 bushels per acre, the results from a number of Illinois trials show no average yield increase (Table 4.04). Especially where yields are poor due to soil and weather problems, the use of Cerone can result in further yield decreases and should not be considered.

Wheat management for best yields

Despite our best efforts at managing wheat, harsh winter weather or wet weather in May and June can spell disaster for the crop, and there may be little that can be done to maintain good yields. To help assure good yields when the weather is favorable, follow these steps:
1. Choose several top varieties.
2. Apply some N and necessary P fertilizer before planting: 18-46-0 can be used to provide both nutrients.
3. Drill the seed on or near the fly-free date, using 30 to 35 seeds per square foot of good-quality seed.
4. Topdress additional N at the appropriate rate in the late winter or early spring, at about the time that the crop breaks dormancy and begins to green up. Application to frozen soil is acceptable, but some N may run off if rain falls on sloping soil before it thaws.
5. Scout for weeds, insects, and diseases beginning in early April, and treat for control only if necessary.
6. Hope for dry weather during and after heading.

Table 4.04. Response of Caldwell Wheat to Cerone Growth Regulator and Tilt Fungicide

Treatment	Southern Illinois[a]	Northern Illinois[b]
	bushels per acre	
−Cerone	55.6	69.0
+Cerone	55.1	69.3
−Tilt	55.2	64.3
+Tilt	57.7	69.5

[a] Average of 7 Cerone trials and 4 Tilt trials at Brownstown and Belleville.
[b] Average of 8 Cerone trials and 4 Tilt trials at Urbana and DeKalb.

Spring wheat

Spring wheat is not well adapted to Illinois. Because it matures more than 2 weeks later than winter wheat, it is in the process of filling kernels during the hot weather typical of late June and the first half of July. Consequently, yields average only about 50 to 60 percent of those of winter wheat.

With the exception of planting time, production practices for spring wheat are similar to those for winter wheat. Because of the lower yield potential, nitrogen rates should be 20 to 30 pounds less than those for winter wheat. Spring wheat should be planted in early spring, as soon as a seedbed can be prepared. If planting is delayed beyond April 10, yields are likely to be very low, and another crop should be considered.

The acreage of spring wheat in Illinois is extremely small, and variety testing has not been extensive. Table 4.05 lists some of the more recent varieties, most of which were developed in Minnesota or other northern states. These have not been tested extensively in Illinois, and as the table shows, yields are likely to vary substantially depending on the year. Any of these varieties is likely to do reasonably well if weather favors spring wheat production, but all will yield quite poorly if the weather is unfavorable.

Rye

Both winter and spring varieties of rye are available, but only the winter type is suitable for use in Illinois. Winter rye is often used as a cover crop to prevent wind erosion of sandy soils. The crop is very winter-hardy, grows late into the fall, and is quite tolerant to drought. Rye generally matures 1 or 2 weeks before wheat. The major drawbacks to raising rye are the low yield potential and the very limited market for the crop. It is less desirable than other small grains as a feed grain.

The cultural practices for rye are the same as for wheat. Planting can be somewhat earlier, and the nitrogen rate should be 20 to 30 pounds less than that for wheat because of lower yield potential. Watch for shattering as grain nears maturity. Watch also for the ergot fungus, which replaces grains in the head and is poisonous to livestock.

Table 4.05. Yields of Spring Wheat Varieties — 1991, 1992, and 1994, DeKalb

Variety	1991	1992	1994	3-year avg.[1]
Butte 86	15	45	55	38
Prospect	22	43	57	41
Wheaton	19	44	56	39
Sharp	16	46	56	39
Gus	20	36	54	36
Grandin	13	42	54	36
Marshall	18	46	56	40
Guard	20	42	51	38

[1] The 1993 trial failed due to late planting.

There has been very little development of varieties specifically for the Corn Belt area, and no yield testing has been done recently in Illinois. Much of the rye seed available in Illinois is simply called common rye; some of this probably descended from Balbo, a variety released in 1933 and widely grown many years ago in Illinois. More recently developed varieties that may do reasonably well in Illinois include **Hancock**, released by Wisconsin in 1979, and **Rymin**, released by Minnesota in 1973.

Triticale

Triticale is a crop that resulted from the crossing of wheat and rye in the 1800s. The varieties currently available are not well adapted to Illinois and are usually deficient in some characteristic such as winterhardiness, seed set, or seed quality. In addition, they are of feed quality only. They do not possess the milling and baking qualities needed for use in human food.

Cultural practices for triticale are much the same as those for wheat and rye. The crop should be planted on time to help winter survival. As with rye, the nitrogen rate should be reduced to reflect the lower yield potential. With essentially no commercial market for this crop, growers should make certain they have a use for the crop before it is grown. Generally when triticale is fed to livestock, it must be blended with other feed grains. Triticale is also used as a forage crop.

A limited testing program at Urbana indicates that the crop is generally lower yielding than winter wheat and spring oats. Both spring and winter types of triticale are available, but only the winter type is suitable for Illinois. Caution must be used in selecting a variety because most winter varieties available are adapted to the South and may not be winter-hardy in Illinois. Yields of breeding lines tested at Urbana have generally ranged from 30 to 70 bushels per acre.

Spring oats

To obtain high yields of spring oats, plant the crop as soon as you can prepare a seedbed. Yield reductions become quite severe if planting is delayed beyond April 1 in central Illinois and beyond April 15 in northern Illinois. After May 1, another crop should be considered, unless the oats are being used as a companion crop for forage crop establishment and yield of the oats is not important.

When planting oats after corn, it will probably be desirable to disk the stalks; plowing will produce the highest yields but is usually impractical. When planting oats after soybeans, disking is usually the only preparation needed, and it may be unnecessary if the soybean residue is evenly distributed. Make certain that the labels of the herbicides used on the previous crop allow oats to be planted; oats are quite sensitive to a number of common herbicides.

Before planting, treat the seed with a fungicide or a combination such as captan plus Vitavax. Several other fungicides and combinations can be used. For more information, see the local Extension office or contact the Department of Plant Pathology, University of Illinois, Urbana, IL. Seed treatment protects the seed during the germination process from seed- and soil-borne fungi. See Chapter 17, "Management of Field Crop Insect Pests."

Oats may be broadcast and disked in but will yield 7 to 10 bushels more per acre if drilled. When drilling, plant at a rate of 2 to 2½ bushels per acre. If the oats are broadcast and disked in, increase the rate by one-half to one bushel per acre.

For suggestions on fertilizing oats, see Chapter 11, "Soil Testing and Fertility."

Varieties

In recent years, Illinois has been a leading state in the development of oat varieties. Excellent progress has been made in selecting varieties with high yield, good standability, and resistance to barley yellow dwarf mosaic virus (also called redleaf disease), which is the most serious disease of oats in Illinois.

Table 4.06 lists the characteristics of oat varieties that are suitable for production in Illinois. Yields of these varieties in Illinois tests are given in Table 4.07.

Winter oats

Winter oats are not as winter-hardy as wheat and are adapted to only the southern third or quarter of the state; U.S. Highway 50 is about the northern limit for winter oats. Because winter oats are somewhat winter-tender and are not attacked by Hessian fly, planting in early September is highly desirable. Experience has shown that oats planted before September 15 are more likely to survive the winter than those planted after September 15. Barley yellow dwarf virus may infect early-planted winter oats, however.

The same type of seedbed is needed for winter oats as for winter wheat. The fertility program should be similar to that for spring oats. Seeding rate is 2 to 3 bushels per acre when drilled.

Development of winter oat varieties has virtually stopped in the Midwest because of the frequent winter kill. Of the older varieties, **Norline, Compact,** and **Walken** are sufficiently winter-hardy to survive some winters in the southern third of the state. All of these varieties were released more than 20 years ago. Walken has the best lodging resistance of the three.

Spring barley

Spring barley is damaged by hot, dry weather, and therefore is adapted only to the northern part of Illinois. Good yields are possible, especially if the crop is planted in March or early April, but yields tend to be

Table 4.06. Characteristics of Spring Oat Varieties Adapted to Illinois Conditions

Name	State, year released	Kernel color	Maturity[a]	Height	Stand-ability	Resistance[b]: Barley yellow dwarf	Leaf rust	Smut
Brawn	Illinois, 1993	yellow	5	medium	good	MR	MR	R
Don	Illinois, 1985	white	0	short	fair	I	S	R
Hazel	Illinois, 1985	grayish	4	medium to short	very good	R	S	S
Larry	Illinois, 1981	yellow	. . .	short	very good	MR	S	S
Newdak	N. Dakota, 1990	white	1	medium	good	MR	MS	R
Ogle	Illinois, 1981	yellow	4	medium	very good	R	S	S
Prairie	Wisconsin, 1992	tan	5	medium	very good	R	MS	I

[a] Days later than Larry.
[b] R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible; I = intermediate.

Table 4.07. Yields and Test Weights of Spring Oat Varieties in Illinois Trials

Variety	DeKalb[1] Yield	DeKalb[1] Test wt.	Urbana[2] Yield	Urbana[2] Test wt.
Brawn	96	31	108	30
Don	84	33	96	32
Hazel	91	33	100	32
Larry	84	32	99	31
Newdak	97	31	102	30
Ogle	99	31	107	30
Prairie	122	31	110	30

[1] Data are 5-year averages: 1989-92 and 1994. The 1993 trial failed.
[2] Data are 6-year averages: 1989-94.

erratic. Markets for malting barley are not established in Illinois, and malting quality may be a problem. Barley can, however, be fed to livestock.

Plant spring barley early — about the same time as spring oats. Drill 1½ to 2 bushels of seed per acre. To avoid excessive lodging, harvest the crop as soon as it is ripe. Fertility requirements for spring barley are essentially the same as for spring oats.

The situation with spring barley varieties is similar to that in spring wheat: Most varieties originate in Minnesota or North Dakota and have not been widely tested or grown for seed in Illinois. Table 4.08 lists results of limited testing with some of the newer varieties at DeKalb, Illinois. Seed for any of these will likely need to be brought in from Minnesota or the Dakotas.

Table 4.08. Yields of Spring Barley Varieties at DeKalb

Variety	5-yr. avg.[1]
Azure	68.7
Hazen	64.6
Manker	60.8
Morex	56.8
Norbert	63.5
Robust	61.2
Excel	56.4

[1] Data are from 1989-92 and 1994. The 1993 trial failed.

Winter barley

Winter barley is not as winter-hardy as the commonly grown varieties of winter wheat and should be planted 1 to 2 weeks earlier than winter wheat. Sow with a drill and plant 2 bushels of seed per acre.

The fertility requirements for winter barley are similar to those for winter wheat except that less nitrogen is required. Most winter barley varieties are less resistant to lodging than are winter wheat varieties. Winter barley cannot stand "wet feet"; therefore, it should not be planted on land that tends to stay wet. The barley yellow dwarf virus is a serious threat to winter barley production.

Varieties

The acreage of winter barley is quite small in Illinois, and variety testing has not been extensive. Based on that limited testing, the following varieties appear to have the best chance of producing a good crop under Illinois conditions. There has been little or no certified seed of these varieties produced in Illinois, but the higher yields make it worthwhile to find seed in another state.

Pennco, released in 1985 by Pennsylvania, is a high-yielding variety with good disease resistance and standability. It is a few days earlier and slightly more winter-hardy than Wysor, and even more winter-hardy (though later in maturity) than **Barsoy,** an old variety that was once common in Illinois.

Wysor, released in 1985 by Virginia, is a high-yielding variety with good disease resistance and winterhardiness.

Chapter 5.

Grain Sorghum

Although grain sorghum can be grown successfully throughout Illinois, its greatest potential, in comparison with other crops, is in the southern third of the state. It is adapted to almost all soils, from sand to heavy clay. Its greatest advantage over corn is tolerance of moisture extremes. Grain sorghum usually yields more than corn when moisture is in short supply, but often yields less than corn under optimum conditions. Grain sorghum is also less affected by late planting and high temperatures during the growing season, but the crop is very sensitive to cool weather and will be killed by even light frost.

While there are available few side-by-side comparisons of corn and grain sorghum in southern Illinois, some indication of the relative yields of these two crops is available from the hybrid trials that are conducted annually. Averaged across ten trials in southern Illinois, corn yielded about 23 bushels per acre more than grain sorghum. In three of the four trials where corn yielded less than 100 bushels per acre, grain sorghum yielded more than corn (Table 5.01). In the six trials where corn yielded more than 100 bushels per acre, corn always outyielded grain sorghum.

Table 5.01. Average Corn and Grain Sorghum Yields from Ten Hybrid Comparison Trials in Southern Illinois from 1990 to 1993

Trial	Corn	Grain sorghum
1	107	56
2	151	90
3	75	135
4	85	44
5	157	91
6	76	114
7	184	139
8	165	127
9	88	118
10	134	108
Average	122	99

This illustrates the advantage that grain sorghum may have under unfavorable weather conditions and indicates that grain sorghum may provide more yield stability than corn if corn often yields less than 100 bushels per acre.

Fertilization

The phosphorus and potassium requirements of grain sorghum are similar to those of corn. The response to nitrogen is somewhat erratic, due largely to the extensive root system's efficiency in taking up soil nutrients. For this reason, and because of the lower yield potential, the maximum rate of nitrogen suggested is about 125 pounds per acre. For sorghum following a legume such as soybeans or clover, this rate may be reduced by 20 to 40 pounds.

Hybrids

The criteria for selecting grain sorghum hybrids are very similar to those for selecting corn hybrids. Yield, maturity, standability, and disease resistance are all important. Consideration should also be given to the market class (endosperm color) and bird resistance, which may be associated with palatability to livestock. Performance tests of commercial grain sorghum hybrids are conducted at three locations in southern Illinois, and results are available (usually in the same report as the commercial corn hybrid yields) in Extension offices in December or January. Because of the limited acreage of grain sorghum in the eastern United States, most hybrids are developed for the Great Plains and may not have been extensively tested under Midwest conditions.

Planting

Sorghum should not be planted until soil temperature is at least 65°F. In the southern half of the state, mid-May is considered the starting date; late May to June 15 is the planting date in the northern half of the state. Such late planting — along with a shorter, cooler growing season — means that hybrids used in northern Illinois must be early-maturing.

Sorghum emerges more slowly than corn and requires a relatively fine and firm seedbed. Planting depth should not exceed 1½ inches, and ¾ to 1 inch is considered best. Because sorghum seedlings are slow to emerge, growers should use caution when using reduced- or no-till planting methods. Surface residue usually keeps the soil cooler and may harbor insects that can attack the crop, causing serious stand losses, especially when the crop is planted early in the season.

Row spacing

Row-spacing experiments have shown that narrow rows produce more than wide rows (Table 5.02). Drilling in 7- to 10-inch rows works well if weeds can be controlled without cultivation, but if weed problems are expected, wider rows that will allow cultivation may be a better choice than drilled grain sorghum.

Plant population

Because grain sorghum seed is small and some planters do not handle it well, there is a tendency to plant based on pounds of seed per acre, rather than by number of seeds. This usually results in overly dense plant populations that can cause lodging and yield loss. Aim for a plant stand of 50,000 to 100,000 plants per acre, with the lower population on droughtier soils. Four to 6 plants per foot of row in 30-inch rows at harvest and 2 to 4 plants per foot in 20-inch rows are adequate. Plant 30 to 50 percent more seeds than the intended stand. Sorghum may also be drilled using 6 to 8 pounds of seed per acre. When drilling, be sure not to use excessive seed rates; plant stands when drilled should not be much higher than those in rows.

Table 5.02. Yield of Grain Sorghum as Affected by Row Spacing in a Missouri Trial

Row spacing	Yield
inches	*bu/acre*
7	121
14	118
21	103
28	98
35	89

NOTE: Data are 3-year averages.

Weed control

Because emergence of sorghum is slow, controlling weeds presents special problems. Suggestions for chemical control of weeds are given in the back of this handbook. As with corn, a rotary hoe is useful before weeds become permanently established.

Harvesting and storage

Timely harvest is important. Rainy weather after sorghum grain reaches physiological maturity may cause sprouting in the head, weathering (soft and mealy grain), or both. Harvest may begin when grain moisture is 20 percent or greater, if drying facilities are available. Sorghum dries very slowly in the field. Because sorghum does not die until frost, the use of a desiccant (sodium chlorate) can reduce the amount of green plant material going through the combine, making harvest easier.

Marketing

Before planting, check on local markets. Because the acreage in Illinois is limited, many elevators do not purchase grain sorghum.

Grazing

After harvest, sorghum stubble may be used for pasture. Livestock should not be allowed to graze for one week after frost because the danger of prussic acid or hydrocyanic acid (HCN) poisoning is especially high. Newly frosted plants sometimes develop tillers high in prussic acid.

Chapter 6.

Cover Crops and Cropping Systems

Cover crops

Rye, wheat, ryegrass, hairy vetch, and other grasses and legumes are sometimes used as winter cover crops in the Midwest. The primary purpose for using cover crops is to provide plant cover for the soil to help reduce soil erosion during the winter and spring. Winter cover crops plowed under in the spring have been shown to reduce total water runoff and soil loss by 50 percent or more, although the actual effect on any one field will depend on soil type and slope, the amount of cover, the planting and tillage methods, and intensity of rainfall. A cover crop can only protect the soil while it or its residue is present and a field planted after a cover crop has been plowed under may lose a great deal of soil if there is intense rainfall after planting. The use of winter cover crops in combination with no-till corn may reduce soil loss by more than 90 percent. Cover crops can also help to improve soil tilth and they can often contribute nitrogen to the following crop.

The advantages of grasses such as rye that are used as cover crops include rapid establishment of ground cover in the fall, vigorous growth, effective recovery of residual nitrogen from the soil, and good winter survival. Most research has shown, however, that corn planted into a grass cover crop often yields less than when grown without a cover crop. There are several reasons for this. Residue from grass crops, including corn, has a high carbon-to-nitrogen ratio, so nitrogen from the soil is often tied up by microbes as they break down the residue. Secondly, a vigorously growing grass crop such as rye can dry out the surface soil rapidly, thereby causing problems with stand establishment under dry planting conditions. When the weather at planting is wet, heavy surface vegetation from a cover crop can also cause soils to stay wet and cool, thus reducing emergence. Finally, chemical substances released during the breakdown of some grass crops have been shown to inhibit the growth of a following grass crop or of grass weeds.

There are several benefits associated with the use of legumes as cover crops. Legumes are capable of nitrogen fixation; so, providing that they have enough time to develop this capability, they may provide some "free" nitrogen — fixed from the nitrogen in the air — to the following crop. Most leguminous plants have a lower carbon-to-nitrogen ratio than grasses, and soil nitrogen will not be tied up as much when legume plant material breaks down. On the negative side, early growth by legumes may be somewhat slower than that of grass cover crops; many of the legumes too are not as winter-hardy as grasses such as rye. Legumes seeded after the harvest of a corn or soybean crop, therefore, often grow little before winter, resulting in low winter survivability, limited nitrogen fixation before spring, and ground cover that is inadequate to protect the soil.

Hairy vetch, at least in the southern Midwest, has usually worked well as a winter cover crop. It offers the advantages of fairly good establishment, good fall growth and vigorous spring growth, especially if it is planted early — during the late summer. When allowed to make considerable spring growth, hairy vetch has provided as much as 80 to 90 pounds of nitrogen per acre to the corn crop that follows. One disadvantage to hairy vetch is its lack of sufficient winterhardiness; severe cold without snow cover will often kill this crop in the northern half of Illinois, especially if it has not made at least 4 to 6 inches of growth in the fall. The 20 to 40 pound per acre seed rate, with seed costs ranging up to $1.00 per pound, can make use of this crop quite expensive; some farmers in the Midwest are growing their own seed to reduce this expense. This crop can also produce a considerable amount of hard seed, which may not germinate for 2 or 3 years, at which time it may be a serious weed, especially in a crop such as winter wheat. Other legume

species that may be used as winter cover crops include mammoth and medium red clovers, alfalfa, and ladino clover.

To get the maximum benefit from a legume cover crop, such crops must be planted early enough to grow considerably before the onset of cold weather in the late fall. The last half of August is probably the best time for planting these cover crops. They can be aerially seeded into a standing crop of corn or soybeans, although dry weather after seeding may result in poor stands of the legume. Some attempts have been made to seed legumes such as hairy vetch into corn at the time of the last cultivation. This may work occasionally, but a very good corn crop will shade the soil surface enough to prevent growth of a crop underneath its canopy, and cover crops seeded in this way will often by injured by periods of dry weather during the summer. All things considered, the chances for successfully establishing legume cover crops are best when they are seeded into small grains during the spring or after small grain harvest, or when they are planted on set-aside or other idle fields.

There is some debate as to the best management of cover crops before planting a field crop in the spring. There is usually a trade-off of benefits: Planting delays will allow the cover crop to make more growth and to fix more nitrogen in the case of legume cover crops, but this extra growth may be more difficult to kill, and it will sometimes result in depletion of soil moisture. Most indications are that killing a grass cover crop several weeks before planting is preferable to killing it with herbicide at the time of planting. Legumes can also produce some of the same problems as grass cover crops, especially if they are allowed to grow past the middle of May.

Recent research at Dixon Springs in southern Illinois has illustrated both the potential benefits and possible problems associated with the use of hairy vetch. In these studies, hairy vetch accumulated almost 100 pounds of dry matter and about 2.6 pounds of nitrogen per acre *per day* from late April to mid-May (Table 6.01). The best time to kill the cover crop with chemicals and to plant corn, however, varied considerably among the three years of the study. On average, corn planted following vetch yielded slightly more when the vetch was killed 1 or 2 weeks before planting. (Table 6.02). Also, corn planted in mid-May yielded more than corn planted in early May, primarily due to a very wet spring in 1 of the 3 years, in which vetch helped to dry out the soil. Vetch also dried out the soil in the other 2 years, but in those years this proved to be a disadvantage because moisture was short at planting. The conclusions from this study were that vetch should normally be killed at least a week before planting, and that planting should not be delayed much past early May because yield decreases due to late planting can quickly overcome the benefits of additional vetch growth.

Table 6.01. Dry Matter and Nitrogen Content of Hairy Vetch Killed by Herbicide at Different Dates at Dixon Springs, 1989–91

Kill date	Dry matter	Nitrogen
	pounds per acre	
Late April	1300	55
Early May	2509	85
Mid-May	3501	115

Although the amount of nitrogen (N) contained in the cover crop may be more than 100 pounds per acre (Table 6.01), the N rate applied to a corn crop following the cover crop cannot be reduced one pound for each pound of N contained in the cover crop. A recent study in Illinois (*Journal of Production Agriculture,* Vol. 7, No. 1, 1994) demonstrated that the economically optimum N rate dropped by only about 20 pounds per acre when a hairy vetch cover crop was used, even though the hairy vetch contained more than 70 pounds of nitrogen per acre. This was due to the fact that yields were slightly higher (about 3 bushels per acre) following cover crops — even at high rates of N (Figure 6.01) — showing that not all of the cover crop benefit was its contribution of N. Even including the higher yield and lower N requirement, however, these researchers concluded that the use of hairy vetch was

Table 6.02. Effect of Vetch Kill Date and Corn Planting Time on Corn Yield at Dixon Springs, 1989–91

	Vetch kill date	
Planting time	1 to 2 weeks before corn planting	At corn planting
Early May	116	114
Mid-May	129	125
Late May	85	. . .

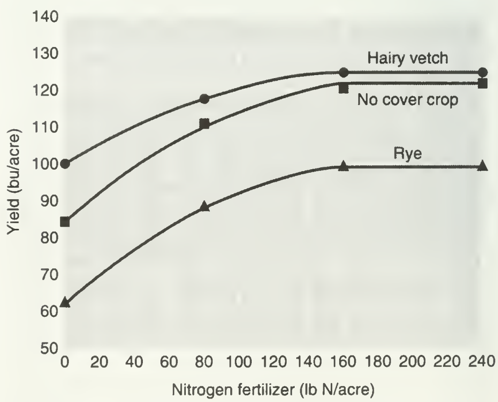


Figure 6.01. The effect of nitrogen (N) fertilizer on grain yield of a summer grain crop (corn or grain sorghum) following either a hairy vetch or rye cover crop or fallow. Data are from five separate trials in Illinois, 1990–1991.

not economically justified. In the same study, rye caused a substantial yield loss (Figure 6.01), and it would be difficult to justify the use of rye based on these results.

Whether or not to incorporate cover-crop residue is debatable, with some research showing no advantages to incorporation and other results showing some benefit. Incorporation may enhance the recovery of nutrients such as nitrogen under some weather conditions; it may offer more weed control options; and it will help in stand establishment, both by reducing competition from the cover crop and by providing a better seedbed. Incorporating cover-crop residue, on the other hand, removes most or all of the soil-retaining benefit of the cover crop during the time between planting and crop canopy development, which is a period of high risk for soil erosion caused by rainfall. Tilling to incorporate residue can also stimulate the emergence of weed seedlings. One alternative to tillage for residue management is to have livestock graze off most of the top growth before planting.

Cropping systems

The term "cropping system" refers to the crops and crop sequences and to management techniques used on a particular field over a period of years. This term is not a new one, but it has been used more often in recent years in discussions about sustainability of our agricultural production systems. Several other terms have also been used during these discussions, and following are working definitions of some of these terms:

- **Allelopathy** is the release of a chemical substance by one plant species that inhibits the growth of another species.
- **Double cropping** is the practice, also known as sequential cropping, of planting a second crop immediately following the harvest of a first crop, thus harvesting two crops from the same field in one year. This is a case of **multiple cropping.**
- **Intercropping** is the presence of two or more crops in the same field at the same time, planted in an arrangement that results in the crops competing with one another.
- **Monocropping** refers to the presence of a single crop in a field. This term is often used incorrectly to refer to growing the same crop year after year in the same field.
- **Relay intercropping** is a form of intercropping in which one crop is planted at a different time than the other. An example would be dropping cover crop seed into a standing soybean crop.
- **Strip cropping** is defined as two or more crops growing in the same field, but planted in strips such that most plant competition is within each crop, rather than between the two crops. This practice has elements of both intercropping and monocropping, with the width of the strips determining the degree of each.

Crop rotations, as a primary aspect of cropping systems, have received a great deal of attention in recent years, with many people contending that most current rotations are unstable and (at least indirectly) harmful to the environment, and are therefore not sustainable. During the past 50 years, the number and complexity of crop rotations used in Illinois have decreased as the number of farms producing forages and small grains has declined. The corn-soybean rotation (with only one year of each crop) is now by far the most common one in the state. Although some consider that this crop sequence barely qualifies as a rotation, it offers several advantages to growing either crop continuously. These benefits include more weed control options and, often, fewer difficult weed problems, less insect and disease buildups, and less nitrogen fertilizer use than with continuous corn. Primarily because of these (and other, some poorly understood) reasons, both corn and soybeans grown in rotation yield about 10 percent more than if they were grown continuously. Growing these two crops in rotation also allows for more flexibility in marketing and it offers some protection against weather- or pest-related problems in either crop.

The specific effects of a corn-soybean rotation on nitrogen requirements are discussed in Chapter 11 of this handbook. Figure 11.06 provides data on the effect of the previous crop on corn yields and on the nitrogen requirements of the corn crop. These data show that, except in the case of alfalfa, most of the effect of the previous crop on corn yields could be overcome with the use of additional nitrogen. Other studies also have shown that the yield differential due to crop rotation can be overcome partially by additional nitrogen, but the differential usually cannot be eliminated.

One frequent question is whether input costs can be reduced by using longer-term, more diverse crop rotations. Studies into this question have compared continuous corn and soybean and the corn-soybean rotation with rotations lasting four or five years that contain small grains and legumes, either as cover crops or as forage feed sources. Like the corn-soybean rotation, certain longer rotations can reduce pest control costs, while including an established forage legume can provide a considerable amount of nitrogen to a succeeding corn crop (Figure 11.06). At the same time, it should be noted that most of the longer-term rotations include forage crops or other crops with smaller, and perhaps more volatile, markets than corn and soybeans. Lengthening rotations to include forages will be difficult unless the demand for livestock products increases. Such considerations will continue to favor production of crops such as corn and soybeans.

Chapter 7. Alternative Crops

Many alternative crops could be grown in Illinois, but have not been produced commercially. A few have been produced on a limited scale and are sold in limited quantity to a local market. Many alternative crops are associated with high market prices or high income potential per acre and thus are eye-catching to farmers that might learn about them. Upon investigation, such crops often have requirements which cannot be met under Illinois conditions, have high costs of production, or have no established or very limited market.

Before production of an alternative crop is undertaken, first study market availability, demand, and growth potential. Crops with limited demand can easily become surplus in supply, driving down previously high prices. Unless alternative crops are desired by large populations, market expansion potential is limited. Delivery to a local market is most desirable, but many alternative crops must be transported great distances to markets — reducing profitability. Market factors must be considered first with alternative crops!

Some alternative crops can be used on-farm, perhaps substituting for livestock feed purchased off the farm. If production is sufficiently low in cost, it may be possible to increase overall farm profitability with production of an alternative crop. The feeding value of alternative crops should be included in such a consideration: While some crops can substitute for protein supplements, they may not result in equal animal gain or performance.

It is possible to produce a number of alternative crops in Illinois, but their optimum yield may be obtained under a different climatic regime. Various types of beans can be grown in Illinois, but because of temperature and rainfall patterns, yield may be impaired, or disease may take a toll on yield or quality of the yield harvested.

Specialized equipment and facilities — or a large supply of inexpensive labor — may be needed to produce an alternative crop. Unless equipment or special facilities are used across many acres of a crop, the cost will be prohibitive. A number of some alternative crops require large labor supplies not available in the Corn Belt. Success of many crops in foreign countries is due to abundant supplies of low-cost labor.

Profitability of producing alternative crops is the fundamental consideration farmers must make. Unless economically viable on-farm consumption is possible, market demand and delivery points will determine income potential from each unit of any crop harvested. Highest yields from any crop will occur in specific environments, but Illinois cannot provide the environment needed by many crops. Equipment or special facilities required to produce alternative crops can be costly, and labor for some crops may not be available at an affordable cost. There are many factors which can take profitability out of producing what may initially appear to be an exceptional farming opportunity.

Table 7.01 provides a list of alternative crops which might be produced on Illinois farms. Information is provided on the crop botany, use, and environmental needs, and potential problems for each crop. In all cases, the crops do not have large or established markets in Illinois. A few may have limited local markets, perhaps requiring the producer to market the crop directly to the consumer. Greater information on the crops listed can be obtained from the publication *Alternative Field Crops Manual* (available from the Center for Alternative Plant and Animal Products, 340 Alderman Hall, University of Minnesota, St. Paul, MN 55108).

The sunflower, canola, and buckwheat crops have been produced on Illinois farms in recent years. Brief overviews of these crops and production practices needed are provided below.

Table 7.01. Alternative Crop Characteristics, Uses, and Considerations

Crop	Botany	Uses	Environmental needs	Potential problems
Adzuki Bean	Legume, indeterminate growth habit, 110 to 120 days to maturity.	Food — confectionery items, fillings for bread.	Similar to soybean and dry-beans.	Limited varieties, disease, limited markets.
Amaranth	Relative of red root pigweed, 5 to 7 ft tall.	Grain, forage, and green leafy vegetable.	Widely adapted to Midwest and western U.S. areas.	Uniform varieties not available; no herbicides labeled for crop; harvest losses; limited markets.
Broomcorn	Annual type of sorghum 6 to 15 ft tall, annual.	Long panicle branches used to make brooms.	Warm summer, soil moist and fertile — widely adapted.	Harvest and curing of fiber is very labor intensive; disease problems exist; limited markets.
Buckwheat	Indeterminate growth; will not die until killed by frost; harvest in 10 to 12 weeks.	Nutritious grain used for human food and livestock; smother crop or green manure.	Cool and moist climate; tolerates low fertility better than other grains.	Limited varieties available; seed shatter easily; limited markets.
Canola	Edible type of rape; spring and winter growth habits available.	Nutritious oil in grain; meal fed to livestock; forage use.	Well-drained fertile soil; cool temperature range; cannot tolerate water-saturated soil.	May not survive winter in Illinois; timely planting in a corn/soybean rotation; seed shatter easily; limited delivery points in the Midwest.
Chickpea	Annual legume up to 40 in. tall; produces protein rich seed; fairly drought resistant.	Soup and salad; can be fed to livestock.	Temperature of 70 to 80°F optimum; fertile soil with good drainage.	Excess water induces disease and lodging; limited markets.
Cowpea	Annual legume, known as blackeye pea, produces protein-rich seed.	Grain, fresh vegetable, or forage for livestock.	Adapted to humid tropics and temperate zones; tolerant of heat and drought, but not frost; needs well-drained soil.	Disease, nematodes and virus problems can occur; specialized harvest equipment required for fresh harvesting; limited markets in the Midwest.
Crambe	Annual herb up to 40 in. tall produces seed with inedible oil used by industry.	Manufacture of plastic, nylon, adhesives, and synthetic rubber.	Cool season, well-drained and fertile soil — cannot tolerate water-saturated soil.	No developed market; seed meal has little value; limited varieties available; no herbicide or insecticide labeled for the crop.
Fababean	Annual legume, takes 80 to 120 days to mature; seedlings frost-tolerant; seed size varies greatly dependent on variety.	Human food; livestock feed; forage or silage.	Cool, moist conditions; hot weather is injurious to crop; well-drained soil; does not tolerate waterlogged soil conditions.	Negligible demand in the U.S., thus limited markets; no insecticide or herbicide labeled for the crop.
Ginseng	Perennial herb prized in the Orient for its medical properties.	In the Far East in soft drinks, toothpaste, tea, and candy; sold as extracts, crystals, and powder capsules, too.	Moist climate; 70 to 90% shade; soil high in organic matter, with pH near 5.5.	Disease and insect problems exist; shade structures, labor, and time make production expensive; harvest is at least 3 years after planting.
Kenaf	Annual fiber crop native to Africa, 8 to 14 ft tall.	Fiber for paper, cardboard, rope, twine, rugs, and bagging; forage.	Widely adapted, but long growing seasons with high temperatures and abundant rainfall yield best.	Limited varieties — none developed for the Midwest; specialized equipment needed for harvest; markets lacking.
Lentil	Cool season legume grain crop, 12 to 20 in. tall; seed varied in color; stems tend to lodge.	Human consumption in soups, stews, and salads.	Cool (seedlings frost-tolerant) temperatures with 10 to 12 in. precipitation annually; soil with good drainage required.	Plants are weak competitors, thus weed control is essential; lodging of stems is likely — slowing harvest; volatile price; limited market opportunities.
Lupine	Annual legume crop with good protein content; older types had bitter alkaloids in them.	Food for humans as flour and pasta; feed for dairy cows, lambs, and poultry, but not swine.	Cool season; relatively tolerant of spring frost; well-drained soil with pH below 7.	Poor competitor with weeds; very few herbicides cleared for use; diseases likely with excess moisture; seed costs are high (3x soybean); limited markets.
Millet	Annual grasses up to 4 ft tall; several types — with proso, foxtail, and some barnyard types grown in the Midwest.	Bird food and livestock feed; hay and silage.	Warm temperatures (frost sensitive); well-drained loamy soil; will not tolerate waterlogged soil or extreme drought.	Limited herbicides labeled; limited markets for grain available through bird food suppliers.
Mung bean	Annual legume; 1 to 5 ft tall; upright or viney types; seed color varies with variety.	Bean sprouts or canned for human food; livestock feed.	Warm season like soybean; fertile, well-drained soil with good internal drainage and pH less than 7.2.	Many broadleaf herbicides damage the crop; pod maturity not uniform; seed costs higher than soybean; limited market opportunities.

Table 7.01. Alternative Crop Characteristics, Uses, and Considerations (cont.)

Crop	Botany	Uses	Environmental needs	Potential problems
Safflower	Annual oilseed which produces a high-quality edible oil low in saturated fatty acids.	Primarily oil, but also protein meal and birdseed.	Warm, sunny, and less than 15 in. rain/year; dry weather during flower and seed fill; deep fertile well-drained soil.	Broadleaf weeds are difficult to control; wet weather can induce disease; in the Corn Belt no established market exists.
Spelt	A wheat relative with protein content similar to oats; has a growth habit like winter wheat.	Feed grain, pasta, and high-fiber cereals; can replace soft red winter wheat in baked goods.	Typical Midwest climates; is reported more winter-hardy than most soft red winter wheat; grows on sandy and poorly drained soils.	Feed value could be lower than oats as test weight is sometimes lower; no established market exists.
Sunflower	Annual; produces high-quality edible oil; 3rd largest oilseed crop in the world.	Vegetable oil, snack food, birdseed, protein meal, soaps, detergent, plastics, adhesives, and paints.	Semi-arid regions, tolerates high and low temperatures; can survive drought but is inefficient water user; grows on wide range of soil types.	Bird, disease, and insect problems can limit yield; modified combine needed for efficient harvest; limited local markets in the Midwest.
Triticale	A man-made crop from the cross of wheat x rye; spring and winter types grow like wheat and rye.	Livestock feedgrain, forage, baked goods (inferior to wheat).	Needs of winter types similar to fall planted wheat and rye; spring types need conditions similar to spring oats, barley, and wheat.	Ergot disease may occur with spring plantings; other diseases may occur; markets limited.

Sunflower

Sunflower is an alternative crop which some Illinois farmers have profitably produced in the past. Interest in the crop seems to be stimulated following drought years which suppress yield of corn and soybeans. Interest has also been related to some government programs that allowed harvest of the crop from some of the set-aside acres. Two kinds of sunflowers can be produced in Illinois: the oil type and confectionery or non-oil type. Production practices for the two types tend to be the same, but end use of the grain differs.

Oilseed sunflower produces a relatively small seed with an oil content of up to 50 percent. The hull on the grain is thin, dark colored, and adheres tightly to the kernel. Oil from this type of sunflower is highly regarded for use as a salad and frying oil. Meal from the kernel is used as a protein supplement in livestock rations. Meal of sunflower is deficient in lysine, and thus except for ruminant animals, it cannot be used as the only source of protein.

The confectionery (non-oil) type of sunflower is used for human and bird food. The seed is larger than the oil type, with a considerably lower oil content. The hull is lighter in color, usually striped, and the hull separates easily from the kernel.

Sunflower planting coincides with that of corn in Illinois. Many hybrids offered for sale will reach physiologic maturity in only 90 to 100 days and thus can be planted following harvest of small grain crops. Use of sunflower as a double-crop may be a good choice if soybean cyst nematode is a pest, because sunflower is not attacked by cyst nematode.

Plant populations of 20,000 to 25,000 plants per acre are suitable for oilseed sunflower types produced on soils with good water-holding capacity. Stands of 16,000 to 20,000 per acre are appropriate for coarser textured soils with low water-holding capacity. The confectionery type sunflower should be planted at lower populations to help ensure production of large seed. Planting of seed should be at 1½- to 2-inch depth, similar to seed placement for corn. Performance will tend to be best in rows spaced at 20 to 30 inches.

A seed moisture of 18 to 20 percent is needed to permit sunflower harvest. Once physiologic maturity of seed occurs (at about 40 percent), a desiccant can be used to speed drying of green plant parts. Maturity of kernels occurs when the backs of heads are yellow, but the fleshy head and other plant parts take considerable time to dry to a level that permits combine harvest. A conventional combine head can be used for harvest, with losses reduced considerably if special panlike attachments extending from the cutter bar are used. Long-term storage of sunflower is feasible, but levels of less than 10 percent moisture need to be maintained.

Locating a market for sunflower is important before producing the crop. A limited number of marketing sites exists for oil type sunflower, but the majority of confectionery sunflowers are produced under contract for a local feed distributor or healthfood store.

Because the head containing seed is exposed at the top of the plant, insects, disease, and birds can be pest problems. The location of sunflower fields relative to wooded areas will have an impact on the extent of bird damage.

Canola (oilseed rape)

Canola is a member of the mustard family, but has unique chemical properties allowing consumption of edible oil and protein-rich meal from the seed. Rape, from which canola was selected, is a crop which has been used as an oilseed in many countries for centuries. Unlike rape, canola has a low erucic acid content in the oil and low levels of glucosinolates in the meal

produced from the seed. Only since 1985 has canola been approved for consumption in the United States.

Varieties of canola with spring and winter growth habits are available, but the winter type is more likely to succeed in Illinois because hot weather occurs during seed production when spring types are grown. Winterhardiness under Illinois conditions has proven to be a problem for the winter types, which are planted in the fall shortly before wheat is typically seeded.

Site selection is critical to successful production of canola, because waterlogged soil cannot be tolerated by the crop. Only fields with good drainage should be used; excess moisture (ponding) will kill the crop.

Planting 2 or 3 weeks in advance of normal wheat planting time is adequate for plant establishment, provided that fall temperatures do not arrive unusually early. The very small seeds need to be planted shallow with a grain drill at a rate of only 5 to 6 pounds per acre. Canola needs adequate time to become established before fall temperatures decline, but does not need to develop excessively. Plants with 8 to 10 leaves are considered adequate in development for winter survival. A tap root 5 to 6 inches deep generally develops with desired levels of topgrowth in the fall.

Soil-fertility needs of canola are similar to winter wheat, with a small amount of nitrogen applied in the fall to stimulate establishment and a larger topdress nitrogen application in the early spring to promote growth. Too much nitrogen available in the fall can delay the onset of dormancy of canola, putting it at greater risk of winter injury. Excess fertility can accentuate lodging tendencies.

Growth of canola in the spring resumes early, with harvest maturity being reached about the same time as winter wheat. Harvest needs to be done in a timely manner, for seeds tend to easily shatter from pods. Only the top portion of the plant containing the seed pods is harvested. Combining works well when seeds reach 10 percent moisture, but further drying of seeds (9 percent or less) and occasional aeration are needed for storage. As seeds are very small, tight wagons, trucks, and bins are needed for transportation and storage of the crop.

Locating a nearby delivery site for canola is presently a problem.

Buckwheat

Nutritionally, buckwheat is a very good grain, with an amino acid composition superior to all cereals, including oats. Producing the crop as a livestock feed is possible, but markets for the grain for human consumption tend to be small. An export market exists in Japan, where noodles are made from the grain.

Buckwheat has an indeterminate growth habit; consequently it grows until frost terminates growth that is most favored by cool and moist conditions. In a short period (75 to 90 days), it can produce grain ready for harvest. High temperatures and dry weather during flowering can seriously limit grain formation on the crop. Little breeding work has been done to enhance yield potential of the crop; it is naturally cross-pollinated and cannot be inbred because of self-incompatibility. A limited number of varieties are available.

Because it produces grain in a short time, buckwheat can be planted as late as July 10 to 15 in northern parts of Illinois and during late July in southern parts of the state. Rapid vegetative growth of the plant provides good competition to weeds. Fertility demands of the crop are not high, so it may produce a better crop than other grains on infertile, poorly drained soils.

With the exception of those that can use the crop for livestock feed, producers should determine market opportunities before planting the crop. A few grain companies in the Midwest handle the crop for export to Japan.

Other crops

There is plenty of opportunity for individuals or small groups to explore production and marketing of the alternative crops mentioned in this section. It is difficult to imagine a substantial shift away from corn, soybeans, and wheat in favor of any of these crops, however. People and livestock require very large amounts of carbohydrates, protein, and edible oil to meet dietary needs. A good balance of these is provided by the crops now grown in Illinois.

Chapter 8.

Hay, Pasture, and Silage

High yields

Thick, vigorous stands of grasses and legumes are needed for high yields. A thick stand of grass will cover nearly all the ground. A thick stand of alfalfa is about 30 plants per square foot at the end of the seeding year, 10 to 15 plants per square foot the second year, and 5 to 7 plants per square foot for the succeeding years.

Vigorous stands are created and maintained by choosing disease- and insect-resistant varieties that grow and recover quickly after harvest, by following good seeding practices, by fertilizing adequately, by harvesting at the optimum time, and by protecting the stand from insects.

Establishment

Spring seeding date for hay and pasture species in Illinois is late March or early April — as soon as a seedbed can be prepared. Exceptions are seedings that are made in a fall-seeded, winter annual companion crop; for such seedings, seed hay and pasture species about the time of the last snow.

Sowing hay and pasture species into spring oats in the spring should be done when the oats are seeded, as early as a seedbed can be prepared.

Spring seedings are more successful in the northern half of Illinois than in the southern half. The frequency of success in the southern one-quarter to one-third of the state indicates that late-summer seedings may be more desirable than spring seedings.

Late-summer seeding date is August 10 in the northern quarter of Illinois, August 30 in central Illinois, and September 15 in the southern quarter of Illinois. Seedings should be made close to these dates, and no more than 5 days later, to assure that the plants become well established before winter. Late-summer seedings that are made extremely early may suffer from drought following germination.

Seeding rates for hay and pasture mixtures are shown in Table 8.06. These rates are for seedings made under average conditions, either with a companion crop in the spring or without a companion crop in late summer. Higher rates may be used to obtain high yields from alfalfa seeded without a companion crop in the spring. Seeding rates higher than described in Table 8.06 have proven economical in northern and central Illinois when alfalfa was seeded as a pure stand in early spring and two or three harvests were taken in the seeding year. In northern and central Illinois, but not in south-central Illinois, seeding alfalfa at 18 pounds per acre has produced yields 0.2 to 0.4 ton higher than seeding at 12 pounds per acre.

The two basic methods of seeding are band seeding and broadcast seeding. With band seeding, a band of phosphate fertilizer (0-45-0) is placed about 2 inches deep in the soil with a grain drill; then the forage seed is placed on the soil surface directly above the fertilizer band (Figure 8.01). Before the forage seeds are dropped, the fertilizer should be covered with soil, which occurs

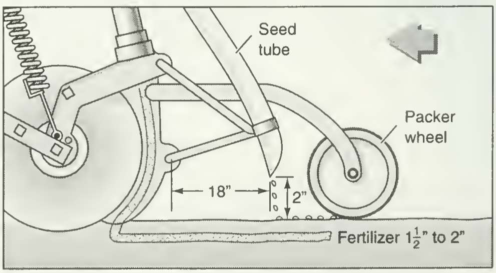


Figure 8.01. Placement of seed and high-phosphate fertilizer with grain drill.

naturally when soils are in good working condition. A presswheel should roll over the forage seed to firm the seed into the soil surface. Many seeds will be placed one-eighth to one-fourth inch deep with this seeding method.

With broadcast seeding, the seed is spread uniformly over a firm, prepared seedbed; then the seed is pressed into the seedbed surface with a corrugated roller. The fertilizer is applied at the early stages of seedbed preparation. The seedbed is usually disked and smoothed with a harrow. Most soil conditions are too loose after these tillage operations and should be firmed with a corrugated roller before seeding. The best seeding tool for broadcast seeding is the double corrugated roller seeder.

Which is the better seeding method? Illinois studies have shown that band seeding often results in higher alfalfa yields than broadcast seedings for August and spring seedings. Seedings on soils that are low in phosphorus yield more from band seeding than from broadcast seeding. Early seeding on cold, wet soils is favored by banded phosphorus fertilization. The greater yield from band seeding may be a response to abundant, readily available phosphorus from the banded fertilizer. Broadcast seedings may yield as high as band seedings when the soils are medium to high in phosphorus-supplying capacity and are well drained, so that they warm up quickly in the spring.

Forage crop seeds are small and should be seeded no deeper than one-eighth to one-fourth inch. The seeds should be in close contact with soil particles. The double corrugated roller seeder and the band seeder with press-wheels roll the seed into contact with the soil and are the best known methods of seeding forages.

Fertilizing and liming before or at seeding

Lime. Apply lime at rates suggested in Figure 11.03, Chapter 11. If rate requirements are in excess of 5 tons, apply half before the primary tillage (in most cases, plowing) and half before the secondary tillage (harrowing or disking). For rates of less than 5 tons, make a single application, preferably after plowing, although applying either before or after plowing is acceptable.

Nitrogen (N). No nitrogen should be applied for legume seedings on soils with an organic-matter content above 2.5 percent. Applying as much as 20 pounds of nitrogen per acre may help assure rapid seedling growth of legume-grass mixtures on soils with less than 2.5 percent organic matter. When seeding a pure grass stand, 50 to 100 pounds of nitrogen per acre in the seedbed are suggested. If band seeding, apply nitrogen with phosphorus through the grain drill. For broadcast seedings, apply broadcast with phosphorus and potassium during seedbed preparation.

Phosphorus (P). Apply all phosphorus at seeding time (Table 11.23 and Table 11.24, page 94) or broadcast part of it with potassium. For band seeding, reserve at least 30 pounds of phosphate (P_2O_5) per acre to be applied at seeding time. For broadcast seeding, broadcast all the phosphorus with the potassium, preferably after primary tillage and before final seedbed preparation.

Potassium (K). Fertilize before or at seeding. Broadcast application of potassium is preferred (Table 11.24 and Table 11.25). For band seeding, you can safely apply a maximum of 30 to 40 pounds of potash (K_2O) per acre in the band with phosphorus. The response to band fertilizer will be mainly from phosphorus unless the K soil test is very low (perhaps 100 pounds per acre or less). For broadcast seeding, apply all the potassium after the primary tillage. You can apply up to 600 pounds of K_2O per acre in the seedbed without damaging seedlings if the fertilizer is incorporated.

Fertilization

Nitrogen. See the chapter titled "Soil Testing and Fertility," the subsection about nitrogen.

Phosphorus. This nutrient may be applied in large amounts, adequate for 2 to 4 years. The annual needs of a hay or pasture crop are determined from yield and nutrient content of the forage harvested (Table 11.24). Grasses, legumes, and grass-legume mixtures contain about 12 pounds of P_2O_5 (4.8 pounds of P) per ton of dry matter. Total annual fertilization needs include the maintenance rate (Table 11.24) and any needed build-up rate (Table 11.23).

Potassium. Because potassium helps the plant convert nitrogen to protein, grasses need large amounts of potassium to balance high rates of nitrogen fertilization. As nitrogen rates are increased, the nitrogen percent in the plant tissue also increases. If potassium is deficient, however, some nitrogen may remain in the plant as nonprotein nitrogen.

Legumes feed heavily on potassium. Potassium, a key element in maintaining legumes in grass-legume stands, is credited with improving winter survival.

Annual potassium needs are determined from yield, nutrient content in the forage that is harvested, and nutrient build-up requirements of a particular soil (Table 11.24 and Table 11.25). Grasses, legumes, and grass-legume mixtures contain about 50 pounds of K_2O (41.5 pounds of K) per ton of dry matter.

Boron (B). Symptoms of boron deficiency appear on second and third cuttings of alfalfa during droughty periods in some areas of Illinois. But yield increases from boron fertilization have been infrequent. Application of boron on soils with less than 2 percent organic matter is recommended for high-yielding alfalfa production in Illinois. If you suspect a boron deficiency, topdress a test strip in your alfalfa fields with 30 pounds per acre of household borax (3.3 pounds of boron). For general application, have boron added to the phosphorus-potassium fertilizer.

Management

Seeding year. Hay and pasture crops seeded into a companion crop in the spring will benefit by early removal of the companion crop. Oats, wheat, or barley should be removed when the grain is in the milk stage. If these small grains are harvested for grain, it is important to remove the straw and stubble as soon as possible. As small-grain yields increase, the underseeded legumes and grasses face greater competition, and fewer satisfactory stands are established by the companion-crop method. Forage seedings established with a companion crop may have one harvest taken by late August in northern Illinois and, occasionally, two harvests by September 10 in central Illinois and by September 25 in southern Illinois.

Spring-seeded hay crops and pastures without a companion crop should be ready for harvest 65 to 70 days after an early April seeding. Weeds very likely must be controlled about 30 days after seeding unless a preemergence herbicide was used. Postemergence herbicides 2,4-DB and Buctril are effective against most broadleaf weeds. Grassy weeds are effectively controlled by Poast. Follow label directions. Leafhoppers often become a problem between 30 to 45 days after an early April seeding and must be controlled to obtain a vigorous, high-yielding stand.

Second and third harvests may follow the first harvest at 35- to 40-day intervals. The last harvest of the season should be in late August for the northern quarter of Illinois, by September 10 for the central section, and by September 20 for the southern quarter.

Established stands. Maximum dry-matter yield from alfalfa and most forages is obtained by harvesting or grazing the first cutting at nearly full bloom and harvesting every 40 to 42 days thereafter until September. This management produces a forage that is relatively low in digestibility. Such forage is suitable for livestock on maintenance, will produce slow weight gain, and can be used in low-performance feeding programs. In contrast, high-performance feeding programs require a highly digestible forage. The optimum compromise between high digestibility and dry-matter yield of alfalfa is to harvest or graze the first cutting at the late-bud to first-flower stage and to make subsequent cuttings or grazings at 32- to 35-day intervals. Rotational grazing is essential to maintaining legumes in pastures. A rotational grazing program of 5 to 6 pastures should provide for 5 to 7 days of grazing and 30 to 35 days of rest. More intensive grazing, using 8 to 11 pastures, 3 to 4 days of grazing, and 30 to 33 days of rest, increases meat or milk production per acre but may not increase individual animal performance. Intensive grazing management is being adopted by many livestock producers in Illinois.

Because high levels of root reserves (sugars and starches) are needed for winter survival and vigorous spring growth, the timing of the fall harvest is critical. Following a harvest, root reserves decline as new growth begins. About 3 weeks after harvesting, root reserves are depleted to a low level, and the top growth is adequate for photosynthesis to support the plant's needs for sugars. From this point, root reserves are replenished gradually until harvest or until the plant becomes dormant in early winter. Harvests made in September and October affect late-fall root reserves of alfalfa more than do summer harvests. After the September harvest, alfalfa needs a recovery period until late October to restore root reserves. On well-drained soils in central and southern Illinois, a "late" harvest may be taken after plants have become dormant in late October or early November.

Pasture establishment

Many pastures can be established through a hay crop program. Seedings are made on a well-prepared, properly fertilized seedbed. If it is intended that the hay crop becomes a pasture, the desired legume and grass mixture should be seeded. When grasses and legumes are seeded together, 2,4-DB or Buctril is a herbicide that can be used for broadleaf weed control. Apply 2,4-DB or Buctril about 30 days after seeding, when the legumes are 2 to 4 inches tall and the weeds less than 4 inches tall.

Pasture renovation

Pasture renovation usually means changing the plant species in a pasture to increase the pasture's quality and productivity. Improving the fertility of the soil is basic to this effort. A soil test helps identify the need for lime, phosphorus, and potassium — the major nutrients important to establishing new forage plants.

Before seeding new legumes or grasses into a pasture, reduce the competition from existing pasture plants. Tilling, overgrazing, and herbicides — used singly or in combination — have proven useful in subduing existing pasture plants.

For many years, tilling (plowing or heavy disking) has been used to renovate pastures; but success has been variable. Major criticisms have been that tilling can cause erosion, that the pasture supply for the year of seeding is usually limited, and that a seeding failure would leave no available permanent vegetation for pasturing or soil protection.

No-till seeding of new pasture plants into existing pastures began when herbicides and suitable seeders were developed. The practice of using a herbicide to subdue existing pasture plants and then seeding with a no-till seeder has proven very successful in many research trials and farm seedings. Following are eight basic steps to no-till pasture renovation.

1. Graze the pasture intensively for 20 to 30 days before the seeding date to reduce the vigor of existing pasture plants.
2. Lime and fertilize, using a soil test as a guide. Soil

pH should be between 6.5 and 7.0. Desirable test levels of phosphorus and potassium vary with soil type; phosphorus should be in the range of 40 to 50 pounds per acre, and potassium in the range of 260 to 300 pounds per acre. For more information, see the chapter titled "Soil Testing and Fertility."

3. One or 2 days before seeding, apply a herbicide to subdue the vegetation. Gramoxone Super (paraquat) and Roundup (glyphosate) are approved for this purpose.
4. Seed the desired species, using high-yielding varieties. Alfalfa and red clover are legumes with high-yield potential and are often the species seeded into a pasture that has a desirable grass species and in which Gramoxone Super is to be used in preference to Roundup. To seed, use a no-till drill that places the seed in contact with the soil.
5. Seedings may be made in early spring throughout the northern two-thirds of Illinois and in late August throughout the southern three-fourths of Illinois.
6. Apply insecticides as needed. Insects that eat germinating seedlings are more prevalent in southern Illinois than in northern Illinois, and an insecticide may be needed. Leafhoppers will usually appear throughout Illinois in early summer and be present during most of the growing season. They must be controlled where alfalfa is seeded, especially in spring-seeded pastures, because leafhopper feeding is devastating to new alfalfa seedlings. Several insecticides are approved; for more information, see the current *Illinois Agricultural Pest Management Handbook* chapter on "Insect Pest Management for Field and Forage Crops." Well-established alfalfa plants are injured but not killed by leafhoppers; red clover and grass plants are not attacked by leafhoppers.
7. Initiate grazing 60 to 70 days after spring seedings and not until the next spring for late-August seedings. Spring-seeded alfalfa and red clover should be at about 50 percent bloom at the first grazing. Alfalfa and red clover that are seeded in late August should be in the late-bud to first-flower stage of growth when grazing begins. Use rotational grazing. Graze 5 to 7 days and rest 28 to 30 days; for greater animal product yield per acre, graze 3 to 4 days and rest 32 to 33 days.
8. Fertilize pastures annually on the basis of estimated crop removal. Each ton of dry matter from a pasture contains about 12 pounds of phosphate (P_2O_5) and 50 to 60 pounds of potash (K_2O). Do not use nitrogen on established pastures in which at least 30 percent of the vegetation is alfalfa, red clover, or both. Because 20 to 80 percent of the nutrients grazed may be returned to the pasture in the form of urine and manure, fertilization rates will be less than for hay production. Rotational and intensive grazing management improves uniformity of distribution of manure and urine on pasture. The efficiency of nutrient recycling is increased and reduces the need for supplemental fertilization. Soil-test pastures thoroughly every four years, and adjust the fertilization program according to soil tests. Usually less phosphate and potash are needed on pastures than hay fields.

Selection of pasture seeding mixture

Alfalfa is the single best species for increasing yield and improving the quality of pastures in Illinois. Red clover produces very well in the first 2 years after seeding but contributes very little after that. Birdsfoot trefoil establishes slowly and increases to 40 to 50 percent of the yield potential of alfalfa. Mixtures of alfalfa at 8 pounds and red clover at 4 pounds per acre or of birdsfoot trefoil at 4 pounds and red clover at 4 pounds per acre have demonstrated high yield. Red clover diminishes from the stand about the third year; and the more persistent species, alfalfa or birdsfoot trefoil, increases to maintain a high yield level for the third and subsequent years.

Pasture fertilization

The yield and quality of many pastures can be improved by fertilization. The soil pH is basic to any fertilization program. Pasture grasses tolerate a lower soil pH than do hay and pasture legumes. For pastures that are primarily grass, a minimal pH should be 6.0. A pH of 6.2 to 6.5 is more desirable because nutrients are more efficiently utilized in this pH range than at lower pH values. Lime should be applied to correct the soil acidity to one-half plow depth. This liming is effective half as long as when a full rate is applied and plowed into the plow layer. Consequently, pastures will usually require liming more often (but at lower rates) than will cultivated fields.

Phosphorus and potassium needs are assessed by a soil test. Without a soil test, the best guess is to apply what the crop removes. Pasture crops remove about 12 pounds of phosphate (P_2O_5) and 50 pounds of potash (K_2O) per ton of dry matter. Very productive pastures yield 5 to 6 tons of dry matter per acre; moderately productive pastures yield 3 to 5 tons; and less productive pastures, 1 to 3 tons. Recycling of nutrients from urine and manure reduces the total nutrients removed from a pasture by 20 to 80 percent, varying with the intensity of pasture management. Soil-test every 4 years to monitor changes in fertility status of pastures.

Pasture management

Rotational grazing of grass pastures results in greater production (animal product yield per acre) than does continuous grazing, except for Kentucky bluegrass pastures. Pastures that include legumes need rotational

grazing to maintain the legumes. A rotational grazing plan that works well is 5 to 7 days of grazing with 28 to 30 days of rest, which requires 5 to 6 fields. This plan provides the high-quality pasture needed by growing animals and dairy cows. A more intense grazing system for high performance livestock and for high animal product per acre is a rotational grazing system of 8 to 11 fields, 3 to 4 days of grazing and 30 to 33 days of rest per pasture field. A less intensive and less productive grazing plan for beef cow herds, dry cows, and stocker animals is the following: 10 days of grazing with 30 days of rest — a plan requiring 4 pastures.

Weed control is usually needed in pastures. Clipping pastures after each grazing cycle helps in weed control, but herbicides may be needed for problem areas. Banvel and 2,4-D are effective on most broadleaf weeds. Banvel is more effective than 2,4-D for most conditions but also has more restrictions. Do not graze dairy animals or feed harvested forage from these fields until 60 days after treatment with Banvel. Remove meat animals from Banvel-treated pastures 30 days before slaughter. Restrictions for 2,4-D apply to milk cows, which should not be grazed on treated pasture for 7 to 14 days after treatment. Thistles can usually be controlled by 2,4-D or Banvel, although repeated applications of the herbicide may be necessary. Multiflora rose may be controlled with Banvel applied in early spring, when the plant is actively growing, but before flower bud formation.

Species and varieties

Alfalfa is the highest-yielding perennial forage crop suited to Illinois, and its nutritional qualities are nearly unsurpassed. Alfalfa is an excellent hay crop species and, with proper management, may be used in pastures, as already mentioned.

Bloat in ruminant animals often is associated with alfalfa pastures. Balancing soil fertility, including grasses in mixtures with alfalfa, maintaining animals at good nutritional levels, and using bloat-inhibiting feed amendments are methods to reduce or essentially eliminate the bloat hazard.

Many varieties of alfalfa are available. Many of these varieties have been developed privately; some were developed at public institutions. Private varieties usually are marketed through a few specific dealers. Not all varieties are available in Illinois.

An extensive testing program has been under way at the University of Illinois for many years. The performance of alfalfa varieties listed in Table 8.01 is based on test data compiled since 1961. A few varieties have been tested every year since then; others have been tested only 3 or 4 years. Each variety in this list, however, has been in tests at least 3 years and is being marketed in Illinois.

Bacterial wilt is one of the major diseases of alfalfa in Illinois. Stands of susceptible varieties usually decline severely in the third year of production and may die out in the second year under intensive harvesting schedules. Moderate resistance to bacterial wilt enables alfalfa to persist as long as 4 or 5 years. Varieties listed as resistant usually persist beyond 5 years.

Phytophthora root rot is a major disease of alfalfa grown on poorly drained soils, primarily in the northern half of Illinois. This disease attacks both seedlings and mature plants. The root develops a black lesion, which progresses and rots the entire root. In mature stands, shortened taproots are a symptom of this disease. Many alfalfa varieties with high-yield performance have resistance or moderate resistance to Phytophthora root rot.

Anthracnose is an important disease in the southern half of Illinois and may be important in northern Illinois during warm, humid weather. The disease causes the stem and leaves to brown, with the tip of the stem turning over like a hook. The fungus causes a stem lesion, usually diamond-shaped in the early stages, which enlarges to completely encircle the stem. Many alfalfa varieties with high-yield performance have resistance or moderate resistance to anthracnose.

Verticillium wilt is a root-rot disease that is similar to bacterial wilt. Verticillium wilt develops slowly, requiring about 3 years before plant loss becomes noticeable. Associated with cool climates and moist soils, this fungus is gradually spreading southward in Illinois. Producers in the northern quarter of Illinois should seek resistant varieties; and producers in the rest of the northern half of the state should observe their fields and consider using resistant varieties when seeding alfalfa. Many alfalfa varieties with high-yield performance have resistance or moderate resistance to verticillium wilt.

Other diseases and insects are problems for alfalfa, and some varieties of alfalfa have particular resistance to these problems. You should question your seed supplier about these attributes of the varieties being offered to you.

Red clover (medium red clover) is the second most important hay and pasture legume in Illinois. Although it does not have the yield potential of alfalfa under good production conditions, red clover can persist in wetter and more acidic soils and under more shade competition than can alfalfa. And, although red clover is a perennial physiologically, root and crown diseases limit the life of red clover to 2 to 3 years. Many new varieties have an increased resistance to root and crown diseases and are expected to be productive for at least 3 years. (See Table 8.02.)

Red clover does not have as much seedling vigor or as rapid a seedling growth rate as alfalfa. Therefore, red clover does not fit into a spring seeding program without a companion crop as well as does alfalfa.

Red clover has more shade tolerance at the seedling stage than does alfalfa; therefore, red clover is recommended for most pasture renovation mixtures where shading by existing grasses occurs. The shade tolerance

Table 8.01. Leading Alfalfa Varieties Tested at Least 3 Years in Illinois

Brand or variety	Bacterial wilt resistance[a]	Percent of yield of check varieties[b]		
		Northern	Central	Southern
120	HR	105.56	104.51	105.14
2833	R	111.6	...	...
2852	HR	104.95	106.1	...
630	HR	104.6	105.37	105.84
636	R	105.39	106.94	104.75
645	HR	110.51	110.23	...
Aggressor	HR	106.74	104.85	102.06
Allegiance	R	100.19	...	106.91
Arrow	HR	107.6	103.66	101.67
Belmont	HR	108.72	...	94.1
Benchmark	HR	112.05	...	...
Cimarron VR	HR	102.87	104.18	105.42
Clipper	HR	107.44	98.79	114.6
Comet	R	...	107.05	...
Crown	R	101.86	105.22	...
Cutter	R	106.93	...	...
Dart	HR	107.03	106.85	98.9
Dawn	R	113.74	107.37	...
DK133	HR	108.76	106.58	86.94
Dominator	HR	110.78	...	...
Echo	R	101.63	102.7	110.27
Elevation	R	107.5	110.91	...
Endure	R	106.72	101	104.22
Epic	R	107.38	109.13	101.09
Fortress	R	106.04	105.68	103.57
GH777	HR	...	106.71	...
Impact	HR	105.5	99.03	...
Jade	HR	...	113.69	...
Magnum III	R	110.7	105.97	...
Mercury	R	116.1	110.1	...
Milkmaker	R	104.56	108.43	95.69
Multiplier	HR	...	111.11	...
Peak	R	109.05	108.53	...
Pioneer BR 5262	HR	107.32	105.65	101.54
Pioneer BR 5373	HR	105.24	106.87	...
Renegade	R	...	107.2	...
Royalty	HR	100.82	108.08	...
Sabre	HR	...	107.72	...
Saranac	R	105.7	102.8	102.1
Surpass	R	103.51	106.13	...
Target II	HR	...	108.47	...
Trident II	HR	...	104.92	...
Vector	R	...	107.16	104.76
Venture	HR	109.4	102.7	...
Vernal	R	100.7	100.03	103.78
Webfoot MPR	HR	112.8	105.15	104.19
WL 225	HR	101.81	101.36	107.17
WL 317	HR	105.47	104.43	101.21
WL 322 HQ	HR	...	104.74	103.42
Wrangler	R	105.76	100.96	105.73

[a] HR = highly resistant; R = resistant; MR = moderately resistant.
[b] Check varieties are Baker, Riley, Saranac AR, and Vernal. The average yield of check varieties equals 100.

of red clover enables it to establish well in companion crops such as spring oats and winter wheat.

There are fewer varieties of red clover than of alfalfa. Private breeders are active in developing more varieties of red clover.

Fewer acres are dedicated to mammoth red clover because its yields have been lower than most of the improved varieties of medium red clover.

Ladino clover is an important legume in pastures, but it is a short-lived species. The very leafy nature of ladino makes it an excellent legume for swine pastures. It is also a very high-quality forage for ruminant animals, but problems of bloat are frequent.

Ladino lacks drought tolerance because its root system is shallower than that of red clover or alfalfa.

Kura clover is a perennial clover with rhizomatous rooting. Kura clover seedlings develop slowly, and general growth is less vigorous than red clover. The rhizomatous rooting may enable this specie to be a useful pasture legume. This clover requires a special Rhizobium inoculum to enable it to fix nitrogen. Evaluations of the specie are in progress.

Birdsfoot trefoil has been popular in permanent pastures in northern Illinois. It has a long life but becomes established very slowly. Seedling growth rate is much slower than that of alfalfa or red clover.

A root rot has made birdsfoot trefoil a short-lived crop throughout southern Illinois. The variety Dawn may have adequate resistance to persist throughout the state (see Table 8.03 for variety yields).

Rooting depth of birdsfoot trefoil is shallower than that of alfalfa, thus birdsfoot trefoil is not as productive during drought.

Crownvetch is well known for protecting very erosive soil areas. As a forage crop, crownvetch is much slower than alfalfa or red clover in seedling emergence, seedling growth rate, early-season growth, and recovery growth. Growth rate is similar to that of birdsfoot trefoil. The potential of crownvetch as a hay or pasture plant seems restricted to very rough sites and soils of low productivity. Crownvetch does not tolerate defoliation (grazing or hay harvesting) as well as alfalfa, red clover, or birdsfoot trefoil.

Sainfoin is a legume that was introduced into the western United States from Russia. In Illinois tests, this species has failed to become established well enough to allow valid comparisons with alfalfa, red clover, and others. Observations indicate that sainfoin has a slow growth and recovery growth rate and is not well suited to the humid conditions in Illinois.

Hairy vetch is a winter annual legume that has limited value as a hay or pasture specie. Low production and its vinelike nature have discouraged much use. Hairy vetch may reseed itself and become a weedy species in small grain fields. Hairy vetch seeded with winter wheat at 22 to 25 pounds per acre has increased the protein yield of wheat-vetch silage. Hairy vetch is a popular cover crop, providing approximately 60 pounds of available nitrogen to a following crop. Hairy vetch should be seeded in September and not killed until mid-May to obtain high nitrogen contributions.

Lespedeza is a popular annual legume in the southern third of Illinois. It flourishes in midsummer when most other forage plants are at low levels of productivity. It survives on soils of low productivity and is low yielding. Even in midsummer, it does not produce as well as a good stand of alfalfa, nor will it encroach on a good alfalfa stand. As alfalfa or other vigorous

Table 8.02. Leading Red Clover Varieties Tested at Least 2 Years in Illinois

Variety	Anthracnose resistance[a]		Powdery mildew resistance	Percent of check yield[b]		
	Northern	Southern		Northern	Central	Southern
Arlington	R	. . .[c]	R	99.89	99.55	99.08
Atlas	R	HR	R	. . .	101.87	96.74
Kenland	S	R	. . .	83.45	100.84	100.88
Kenstar	S	R	. . .	85.91	106.36	91.4
Marathon	R	MR	. . .	102.79	110.72	108.71
Redland	MR	R	R	101.19	100.06	102.21
Redland II	R	R	R	108.88	106.81	104.86
Redland III	R	R	R	103.56	99.5	. . .
Renegade	R	R	. . .	95.67	98.3	99.89
Ruby	R	R	. . .	109.05	105.05	99.88

[a] HR = highly resistant; R = resistant; MR = moderately resistant; S = susceptible.
[b] The check variety is Arlington. The check variety yield equals 100.
[c] Data not available.

Table 8.03. Leading Birdsfoot Trefoil Varieties Tested at Least 3 years in Illinois

Variety	Winter-hardiness[a]	Percent of check yield[b]		
		Northern	Central	Southern
Au Dewey	SH	. . .	101.54	100.45
Bonnie	MH	. . .	105.61	107.39
Carroll	H	112.28	97.19	95.43
Dawn	MH	109.48	99.61	96.16
Empire	MH	102.66	92.86	87.23
Fergus	H	. . .	111.01	104.76
Georgia I	SH	. . .	98.28	91.72
Kalo	SH	. . .	85.58	78.59
Leo	MH	101.14	98.62	98.9
Mackinac	H	102.91	94.91	. . .
Maitland	H	99.48	106.56	. . .
Norcen	H	110.19	107.07	108.33
Viking	H	90.46	100.32	103.89

[a] Winterhardiness ratings: H = hardy; MH = moderately hardy; SH = slightly hardy; . . . = information not available.
[b] Check varieties are Dawn and Viking. The average yield of check varieties equals 100.

pasture plants fade out of a pasture, lespedeza may enter it.

Inoculation

Legumes — such as alfalfa, red clover, kura clover, crownvetch, hairy vetch, ladino, and birdsfoot trefoil — can meet their nitrogen needs from the soil atmosphere if the roots of the legume have the correct Rhizobium species and favorable conditions of soil pH, drainage, and temperature. Rhizobium bacteria are numerous in most soils; however, the species needed by a particular legume species may be lacking.

There are seven general groups and some other specific strains of Rhizobium, with each group specifically infecting roots of plants within its corresponding legume group and some specific strains infecting only a single legume species. The legume groups are (1) alfalfa and sweet clover; (2) true clovers (such as red, ladino, white, and alsike); (3) peas and vetch (such as field pea, garden pea, and hairy vetch); (4) beans (such as garden and pinto); (5) cowpeas and lespedeza; (6) soybeans; and (7) lupines. Some of the individual Rhizobium strains are specific to (1) birdsfoot trefoil; (2) crownvetch; (3) kura clover; or (4) sainfoin.

Grasses

Cool-season perennials

Timothy is a popular hay and pasture grass in Illinois, although it is not as high yielding and has less midsummer production than smooth bromegrass or orchardgrass. A cool-season species, it is best suited to the northern half of Illinois. There are several promising new varieties (Table 8.04).

Smooth bromegrass is probably the most widely adapted high-yielding grass species for northern and central Illinois. Smooth bromegrass combines well with alfalfa or red clover. It is productive but has limited summer production when moisture is lacking and temperatures are high. It produces well in spring and fall and can utilize high-fertility programs. There are several improved varieties, and breeding work continues (Table 8.04).

Orchardgrass is one of the most valuable grasses used for hay and pasture in Illinois. It is adapted throughout the state, being marginally winter-hardy for the northern quarter of the state. Orchardgrass heads out relatively early in the spring and thus should be combined with alfalfa varieties that flower early. One of the more productive grasses in midsummer, it is a high-yielding species and several varieties are available (Table 8.04).

Reed canarygrass is not widely used, but it has growth attributes that deserve consideration. Reed canarygrass is the most productive of the tall, cool-season perennial grasses that are well suited to Illinois hay and pasture lands. Tolerant of wet soils, it also is one of the most drought-resistant grasses and can utilize high fertility. It is coarser than orchardgrass or smooth bromegrass and can be as coarse as tall fescue when mature. Grazing studies indicate that, under proper management, reed canarygrass can produce good weight gains on cattle equal to those produced by smooth bromegrass, orchardgrass, or tall fescue.

Table 8.04. Leading Grass Varieties Tested at Least 2 Years in Illinois

Species variety	Percent of check yield[a]		
	Northern	Central	Southern
Kentucky bluegrass			
Dormie	71.3	86.45	...
Orchardgrass			
Benchmark	...	102.42	101.85
Crown	110.10	98.92	97.42
Dart	107.53	105.21	95.44
Dawn	...	102.14	94.38
Justus	...	100.3	109.7
Potomac	95.172	96.188	98.81
Rough Rider	...	103.34	...
Perennial and intermediate ryegrass ryegrass-fescue hybrids			
Amazon	...	106.89	...
Bison	...	107.54	...
Reed canarygrass			
Palaton	115.51	122.37	104.95
Venture	109.32	127.71	105.59
Rescuegrass			
Matua	...	100.06	...
Smooth bromegrass			
FS Beacon	107.34	102.91	113.95
Lincoln	92.28	107.79	101.84
Rebound	90.74	104.6	100.16
Tall fescue			
AU-Triumph	...	121.29	94.32
Johnstone	113.75	116.31	100.72
Kenhy	107.99	122.55	104.53
Ky-31	107.32	119.53	97.37
Martin	115.72	121.74	109.45
Mozark	109.31	128.25	104.51
Timothy			
Richmond	103.46	95.79	101.39
Timfor	...	111.19	98.48

[a] Check varieties are Potomac orchardgrass and Lincoln smooth bromegrass. The average yield for check varieties equals 100.

Reed canarygrass should be considered for grazing during spring, summer, and early fall. Cool temperatures and frost retard growth and induce dormancy earlier than with tall fescue, smooth bromegrass, or orchardgrass. New low-alkaloid varieties have improved animal performance (Table 8.04).

Tall fescue is a high-yielding grass (Table 8.04). It is outstanding in performance when used properly and is a popular grass for beef cattle in southern Illinois. Because it grows well in cool weather, tall fescue is especially useful for winter pasture; and it is also most palatable during the cool seasons of spring and late fall. A fungus living within the plant tissue (endophyte) has a major influence on the lower palatability and digestibility of this grass during the warm summer months. Varieties are available that are fungus-free or low in fungus. Tall fescue varieties that are low in endophyte fungus and are productive in Illinois are listed in Table 8.05. Tall fescue is marginally winter-hardy when used in pastures or hay crops in the northern quarter of the state. A more extensive list of hay, pasture, and silage crop varieties is given in Table 8.05.

Rescuegrass, variety Matua, has been introduced to Illinois markets in recent years from New Zealand. Matua establishes well but is moderately winter-hardy, suffering injury during severe winters.

Warm-season annuals

Sudangrass, sudangrass hybrids, and sorghum-sudangrass hybrids are annual grasses that are very productive during the summer. These grasses must be seeded each year on a prepared seedbed. Although the total-season production from these grasses may be less than that from perennial grasses with equal fertility and management, these annual grasses fill a need for quick, supplemental pastures or green feed. These tall, juicy grasses are difficult to make into high-quality hay. Sudangrass and sudangrass hybrids have finer stems than the sorghum-sudan hybrids and thus will dry more rapidly; they should be chosen for hay over the sorghum-sudan hybrids. Crushing the stems with a hay conditioner will help speed drying. These crops may be used for silage, green chop, or pasture more effectively than for hay.

Sudangrass, sudangrass hybrids, and sorghum-sudangrass hybrids produce prussic acid, a compound that is toxic to livestock. Prussic acid is the common name for hydrogen cyanide (HCN). The compound in sorghum plants that produces HCN is dhurrin. Two enzymes are required to hydrolyze dhurrin to HCN. The microflora in the rumen of ruminant animals are capable of enzymatic breakdown of dhurrin, producing HCN. The concentration of dhurrin is highest in young tissue, with more found in leaves than in stems. There is more dhurrin in the forage of grain or forage sorghums than in sorghum-sudangrass hybrids, and more in sorghum-sudangrass hybrids than in sudangrass hybrids or sudangrass.

Sudangrass and sudangrass hybrids are considered safe for grazing when they are 18 inches tall. The sorghum-sudangrass hybrids should be 24 inches tall before grazing is permitted. Very hungry cattle or sheep should be fed other feeds that are low in prussic-acid potential before turning them onto a lush sudangrass or sorghum-sudangrass pasture. This prefeeding will prevent rapid grazing and a sudden influx of forage that contains prussic acid. These animals can tolerate low levels of prussic acid because they can metabolize and excrete the HCN.

Frost on the crops of the sorghum family breaks cell walls and permits the plant enzymes to come into contact with dhurrin and HCN to be released rapidly. For this reason, it is advisable to remove grazing ruminant livestock from freshly frosted sudangrasses and sorghums. When the frosted plant material is thoroughly dry, usually after 3 to 5 days, grazing can resume. Grazing after this time should be observed closely for new tiller growth, which will be high in dhurrin; and livestock should be removed when there is new tiller growth that is being grazed.

The sorghums can be ensiled. The fermentation of ensiling reduces the prussic acid potential very sub-

Table 8.05. Hay, Pasture, and Silage Crop Varieties

Crop	Variety	Origin	Use
Ladino clover	Merit	Iowa State University	Pasture
Birdsfoot trefoil	AU Dewey	Auburn University	Hay and pasture
	Bonnie	Deer Creek Seeds	Hay and pasture
	Carroll	Iowa State University	Hay and pasture
	Dawn	University of Missouri	Pasture
	Empire	Cornell University	Pasture
	Fergus	University of Kentucky	Hay and pasture
	Georgia I	University of Georgia	Hay and pasture
	Kalo	Oregon State University	Hay and pasture
	Leo	McDonald College, Quebec	Hay and pasture
	Mackinac	Michigan State University	Hay and pasture
	Maitland	University of Guelph, Ontario	Hay and pasture
	Norcen	Northcentral States Agr. Exp. Stations	Hay and pasture
	Viking	Cornell University	Hay and pasture
Crownvetch	Chemung	New York	Erosion and pasture
	Emerald	Iowa	Erosion and pasture
	Penngift	Pennsylvania	Erosion and pasture
Orchardgrass	Benchmark	FFR Cooperative	Hay and pasture
	Comet	Northrup King	Hay and pasture
	Crown	AgriPro	Hay and pasture
	Dart	Land O'Lakes, Inc.	Hay and pasture
	Dawn	Land O'Lakes, Inc.	Hay and pasture
	Justus	International Seeds, Inc.	Hay and pasture
	Latar		Hay and pasture
	Pennlate	USDA/Penn State University	Hay and pasture
	Potomac	USDA/University of Maryland	Hay and pasture
	Rough Rider	Forbes Seed & Grain, Inc.	Hay and pasture
	Warrior	Olsen-Fennell Seeds, Inc.	Hay and pasture
Perennial Ryegrass	Amazon	Willamette Seed Co.	Hay and pasture
	Bison	International Seeds, Inc.	Hay and pasture
	Linn		Hay and pasture
Reed Canarygrass	Palaton	Land O'Lakes, Inc.	Hay and pasture
	Venture	Land O'Lakes, Inc.	Hay and pasture
Rescuegrass	Matua	New Zealand	Hay and pasture
Smooth Bromegrass	FS Beacon	Land O'Lakes, Inc.	Hay and pasture
	Lincoln	University of Nebraska	Hay and pasture
	Rebound	S. Dakota State University	Hay and pasture
Tall fescue	AU-Triumph	Auburn University	Pasture, low in endophyte fungus
	Fawn	Oregon State University	Pasture
	HiMag	Univ. Missouri	Pasture, low in endophyte fungus
	Johnstone	USDA/University of Kentucky	Pasture, low in endophyte fungus
	Kenhy	USDA/University of Kentucky	Pasture, low in endophyte fungus
	Ky-31	University of Kentucky	Pasture
	Martin	University of Missouri	Pasture, low in endophyte fungus
	Mozark	University of Missouri	Pasture, low in endophyte fungus
Timothy	Clair	USDA/University of Kentucky	Hay
	Climax	Canada Department of Agriculture	Hay
	Richmond	Pickseed West	Hay
	Timfor	Northrup King	Hay
Eastern Gamagrass	Iuka		Pasture and silage
	Pete	Soil Conservation Service, Kansas	Pasture and silage
Switchgrass	Blackwell	Kansas	Pasture and hay
	Cave-in-Rock	Illinois	Pasture and hay
	Kanlow	Kansas	Pasture and hay
	Pathfinder	Nebraska	Pasture and hay
	Trailblazer	Nebraska	Pasture and hay
Big bluestem	Champ	Nebraska	Pasture and hay
	Kaw	Kansas	Pasture and hay
	Pawnee	Nebraska	Pasture and hay
	Roundtree	Soil Conservation Service, Missouri	Pasture and hay
Caucasian bluestem	Caucasian	Russia	Pasture and hay
Indiangrass	Holt	Nebraska	Pasture and hay
	Nebraska 54	Nebraska	Pasture and hay
	Osage	Kansas	Pasture and hay
	Oto	Nebraska	Pasture and hay
	Rumsey	Soil Convervation Service, Missouri	Pasture and hay

stantially. This method is the safest for using feed that has a questionably high prussic acid potential.

Harvesting these crops as hay is also a safe way of using a crop with questionably high levels of prussic-acid potential.

Toxic levels of prussic acid (HCN) vary. Some workers report toxicity at 200 ppm HCN of tissue dry weight, while others report moderate toxicity at 500 to 750 ppm HCN of tissue dry weight. Laboratory diagnostic procedures can determine relative HCN potential. An alkaline picrate solution is commonly used to detect HCN in plant tissue.

Millets are warm-season annual grasses that are drought tolerant. Four commonly known millets are pearlmillet (*Pennisetum typhoides* [Burm.] Stapf & C.E. Hubb.), browntop millet (*Panicum ramosum* L.), foxtail or Italian millet (*Setaria italica* [L.] Beav.), and Japanese millet (*Echinochloa crusgalli* var. *frumentacea* [Roxb.] W.F. Wight). Pearlmillet has been evaluated in grazing trials and is a suitable alternative for summer annual pastures.

Pearlmillet requires a warmer soil for rapid establishment than does sudangrass. Seedings should be delayed until the seedbed averages 70°F.

Pearlmillet does not have a prussic-acid potential as does sudangrass, nor is pearlmillet as susceptible to leaf diseases. Pearlmillet is more drought tolerant than is sudangrass, thus producing more pasture during the hot, dry periods of late summer.

Forage mixtures

Mixtures (Table 8.06) of legumes and grasses usually are desirable. Yields tend to be greater than with either the legume or the grass alone. Grasses are desirable additions to legume seedings to fill in where the legume ceases to grow, to reduce soil erosion, to increase the drying rate, to reduce legume bloat, and perhaps to improve animal acceptance. Mixtures of two or three well-chosen species usually yield more than mixtures that contain five or six species, some of which are not particularly well suited to the soil, climate, or use.

Warm-season perennials

Warm-season perennial grasses also are known as native prairie grasses. These prairie grasses normally provide ample quantities of fair- to good-quality pasture during midsummer when cool-season perennials are low yielding and often of low quality. Switchgrass, big bluestem, and indiangrass have been the more popular prairie grasses for use in Illinois.

Switchgrass (*Panicum virgatum* L.) is a tall, coarse-stemmed grass with long, broad leaves that grows 3 to 5 feet tall, with short rhizomes. It is not as palatable as smooth bromegrass. It is native to the Great Plains.

In Illinois, switchgrass starts growing in May but makes most of its growth in June to August. Switchgrass is one of the earliest maturing prairie grasses. Grazing or harvesting should leave a minimum of a 4- to 6-inch stubble. Close grazing or harvesting quickly diminishes the stand.

Switchgrass needs abundant moisture and fertility for maximum growth. Because switchgrass is tolerant of moist soils, it is often used in grass waterways.

Varieties. Blackwell, Caddo, Kanlow, Nebraska 28, Pathfinder, and Trailblazer were selected in the southern and central Great Plains. Trailblazer, released in 1985, is more digestible than the other varieties. Cave-in-Rock was selected from southern Illinois in 1958 and released by the Soil Conservation Service, Elsberry, Missouri, in 1972. Cave-in-Rock has yielded well in Illinois trials.

Switchgrass should be seeded in mid-April to early May. A continuous supply of soil moisture is needed for germination and early seedling development. Precipitation during the first 10 days following seeding has beeen more important for the establishment of switchgrass than the seeding date.

A seeding rate of 6 pounds of pure live seed (PLS) per acre of switchgrass is adequate if weeds are controlled and precipitation is favorable. Increasing the seeding rate increases the number of seedlings established but has little effect on forage yield or forage quality of established stands.

Frequent grazing or hay harvesting — more often than every 6 weeks — reduces the yield and vigor of switchgrass. A harvest may be taken after frost without reducing yield and vigor the following year.

Crude protein and digestible dry matter of switchgrass decline with maturity. Animal gains on switchgrass may be less than on big bluestem or indiangrass.

Switchgrass, indiangrass, and big bluestem yield well as pasture plants. A major portion of the growth occurs after July 1, and nearly all growth from these grasses is completed by August 1 in southern Illinois. The dry matter yield of switchgrass is greater than that of indiangrass and big bluestem.

The crude protein content of switchgrass is higher than indiangrass or big bluestem at comparable maturities during the pasture season. The crude protein values range from 3.4 to 6.4 percent for the major yield of the season. These values are very low if these forages are the only protein source for cattle, sheep, or horses. Big bluestem tends to have a higher crude protein content than indiangrass.

The digestible dry matter of warm-season perennial grasses tends to be below 50 percent, which is below the maintenance level for pregnant beef cows. They may need supplemental feed when pasturing on switchgrass. Indiangrass and big bluestem tend to be a little higher in digestibility than switchgrass, but they are marginal for maintenance of pregnant beef cows. Dry-matter digestibility may be underestimated by *in vitro* analysis methods.

Warm-season perennial grasses may yield 5.5 to 7.5 tons of hay dry matter per acre throughout Illinois.

Big bluestem (*Andropogon gerardii* Vitman) grows to

Table 6.00. Forage Seed Mixture Recommendations, All Entries Given in Pounds per Acre

For hay crops

Northern, Central Illinois		Southern Illinois	
Moderately to well-drained soils			
Alfalfa	12	Alfalfa	8
		Orchardgrass	4
Alfalfa	8		
Bromegrass	6	Alfalfa	8
		Tall fescue	6
Alfalfa	8		
Bromegrass	4		
Timothy	2		
Alfalfa	8		
Timothy	4		
Poorly drained soils			
Red clover	8	Red clover	8
Timothy	4	Bromegrass	6
Red clover	8	Reed canarygrass	8
Bromegrass	6	Alsike clover	4
Alsike clover	5	Tall fescue	6
Timothy	4	Alsike clover	4
Reed canarygrass	8	Redtop	4
Alsike clover	3	Alsike clover	4
Birdsfoot trefoil	5		
Timothy	2		
Droughty soils			
Alfalfa	8	Alfalfa	8
Bromegrass	6	Orchardgrass	4
Alfalfa	8	Alfalfa	8
Tall fescue[a]	6	Tall fescue	6
		Alfalfa	8
		Bromegrass	6

For horse pastures

Northern, Central Illinois		Southern Illinois	
Moderately to well-drained soils			
Alfalfa	8	Alfalfa	8
Smooth bromegrass	6	Orchardgrass	3
Kentucky bluegrass	2	Kentucky bluegrass	5
Poorly drained soils			
Red clover	8	Red clover	8
Smooth bromegrass	6	Orchardgrass	6
Kentucky bluegrass	2	Kentucky bluegrass	5
Timothy	2		

Central Illinois

Moderately to well-drained soils		*Poorly drained soils*	
Alfalfa	8	Ladino clover	½
Orchardgrass	3	Orchardgrass	6
Kentucky bluegrass	2	Kentucky bluegrass	2

For hog pastures

All soil types, anywhere in Illinois

Alfalfa	8
Ladino clover	2

For warm-season perennial grasses

Moderately to well-drained and droughty soils,[b] anywhere in Illinois

Switchgrass	6	Big bluestem	5
		Indiangrass	5
Eastern gamagrass	12		
		Switchgrass	2
Big bluestem	10	Big bluestem	4
		Indiangrass	4
Caucasian bluestem	3		
Indiangrass	10		

For rotation and permanent pastures

Northern, Central Illinois		Southern Illinois	
Moderately to well-drained soils			
Alfalfa	8	Alfalfa	8
Bromegrass	5	Orchardgrass	4
Timothy	2		
		Alfalfa	8
Alfalfa	8	Tall fescue	6
Orchardgrass[a]	4		
		Tall fescue	8
Alfalfa	8	Ladino clover	½
Orchardgrass[a]	4		
Timothy	2	Alfalfa	8
		Bromegrass	6
Orchardgrass[a]	6	Timothy	2
Ladino clover	½		
		Orchardgrass	6
Red clover	8	Ladino clover	½
Ladino clover	½		
Orchardgrass[a]	4	Tall fescue	10
Red clover	8	Orchardgrass	8
Ladino clover	½		
Tall fescue	6-8	Red clover	8
		Ladino clover	½
Birdsfoot trefoil	5	Orchardgrass	4
Timothy	2		
		Red clover	8
Ladino clover	½	Ladino clover	½
Bromegrass	8	Tall fescue	6-8
Tall fescue	10		
Orchardgrass[a]	8		
Poorly drained soils			
Alsike clover	3	Alsike clover	2
Ladino clover	¼	Ladino clover	½
Timothy	4	Tall fescue	8
Birdsfoot trefoil	5	Alsike clover	3
Timothy	2	Ladino clover	½
		Reed canarygrass	8
Reed canarygrass	8		
Alsike clover	3		
Ladino clover	¼-½		
Alsike clover	2		
Ladino clover	½		
Tall fescue	8		
Droughty soils			
Alfalfa	8	Alfalfa	8
Bromegrass	5	Orchardgrass	4
Alfalfa	8	Alfalfa	8
Orchardgrass[a]	4	Tall fescue	6
Alfalfa	8	Red clover	8
Tall fescue	6	Ladino clover	½
		Orchardgrass[a]	4
Red clover	8		
Ladino clover	½	Red clover	8
Orchardgrass	4	Ladino clover	½
		Tall fescue	6-8
Red clover	8		
Ladino clover	½		
Tall fescue	6-8		

For pasture renovation

Northern, Central Illinois		Southern Illinois	
Moderately to well-drained soils			
Alfalfa	8	Alfalfa	8
Red clover	4	Red clover	4
Poorly drained soils			
Birdsfoot trefoil	4	Alsike	2
Red clover	4	Ladino clover	½
		Red clover	4

[a] Central Illinois only.
[b] Not recommended for poorly drained soils.

4 to 7 feet tall and is a sod-forming, warm-season perennial grass. It was a major contributor to the development of the deep, dark, prairie soils of Illinois. This perennial has short rhizomes, but it makes a very tough sod. Big bluestem thrives on moist, well-drained loam soils of relatively high fertility. It is one of the dominant grasses of the eastern Great Plains and is found in association with little bluestem, switchgrass, and indiangrass. Big bluestem establishes slowly from seed.

Big bluestem begins growth in May and makes a large part of its growth in late July through August. Grazing should leave a 6-inch stubble to prevent loss of stand.

This grass is palatable and nutritious in its early stages of growth. It withstands close grazing late in the season if it is protected from close grazing early in the season. Good hay may be made if harvested before seed heads emerge. Seed matures in late September and October.

Roundtree big bluestem was released by the Soil Conservation Service and the Missouri Agricultural Experiment Station in 1983. Other varieties of big bluestem are Champ, Kaw, and Pawnee. Other bluestem varieties include Plains (Yellow Bluestem), released by the Oklahoma Agricultural Experiment Station in 1970, and King Ranch.

Seedings should be made from mid-May to mid-June at 10 pounds of pure live seed (PLS) per acre. Seed at one-fourth inch deep, on a prepared seedbed that has been firmed with a corrugated roller. Use no nitrogen during the seeding year. See Table 8.05 for a list of varieties and Table 8.07 for yield information.

Indiangrass (*Sorghastrum nutans* [L.] Nash) is a sod-forming grass with a deep, extensive root system with short rhizomes. It is adapted to deep, well-drained soils.

Indiangrass produces fair- to good-quality forage during the summer months. Grazing months are July through mid-September. Harvest indiangrass for hay at the early boot stage. Begin grazing after the plant reaches 18 inches in height. Graze to a minimum of a 10-inch stubble.

Varieties are Holt, from the Nebraska Agricultural Experiment Station; Osage, from the Kansas Agricultural Experiment Station; Oto, from the Nebraska Agricultural Experiment Station; and Rumsey, from a native stand in south-central Illinois.

Seedings should be made from mid-May to mid-June at 10 pounds of pure live seed (PLS) per acre. Seed at one-fourth inch deep, on a prepared seedbed that has been firmed with a corrugated roller. Use no nitrogen during the seeding year. See Table 8.05 for a list of varieties and Table 8.07 for yield information.

Eastern gamagrass (*Tripsacum dactyloides* [L.]. L.) is related to corn. The seed heads have the female flowers on the lower portion and the male flowers above. It grows in large clumps in low areas, is quite palatable, and often is destroyed by close grazing. Eastern gamagrass produces a large tonnage of forage and can be used for hay or silage.

Seedings should be made from mid-May to mid-June at 12 pounds of pure live seed (PLS) per acre. Seed at one-fourth inch deep, on a prepared seedbed that has been firmed with a corrugated roller. Use no nitrogen during the seeding year. See Table 8.05 for a list of varieties and Table 8.07 for yield information.

Caucasian bluestem or old word bluestems (*Bothriochloa caucasica* C.E. Hubb.), a perennial bunchgrass, is an introduction from Russia that shows promise as a pasture and hay grass in Illinois. It is easily established from seed and makes good growth even if moisture supplies are low. It bears an abundance of small, viable seed that shatter readily.

Seedings should be made from mid-May to mid-June at 3 pounds of pure live seed (PLS) per acre. Seed at one-fourth inch deep, on a prepared seedbed that has been firmed with a corrugated roller. Use no nitrogen during the seeding year. See Table 8.05 for a list of varieties and Table 8.07 for yield information.

Table 8.07. Species and Varieties of Warm-Season Perennial Grasses at Dixon Springs

Species/variety[a]	1981	1990	Average
	dry matter, tons per acre		
Switchgrass/ Cave-in-Rock	4.50	6.43	5.47
Eastern gamagrass/ Pete	8.25	6.14	7.20
Big bluestem/ Roundtree	5.44	4.23	4.84
Caucasian bluestem	3.73	3.42	3.58
Indiangrass/ Rumsey	5.95	6.11	6.03

[a] Each variety is harvested twice a year.

Establishment of warm-season perennial grasses

Establishment of warm-season perennial grasses is slow. Seedings need to be made early in the season, from April through June, to allow adequate time for the seedlings to become well established. Atrazine (at 2 pounds of active ingredients per acre) may be applied to the surface after seeding big bluestem. Switchgrass and indiangrass seedlings are damaged by atrazine.

Suggested seeding rates are 6 pounds of PLS per acre of switchgrass and 10 pounds of PLS per acre of big bluestem and indiangrass. Do not graze until plants are well established, at least one year old. Weeds may be reduced during seeding year by clipping. The first clipping should occur about 60 days after seeding at a height of 3 inches. Later clippings should be at no less than 6-inch stubble height. Do not clip after August 1.

Seedings should be made on prepared seedbeds that are very firm. The drill or seeder must be able to handle the seed, because seeds of indiangrass and big bluestem are light and feathery. Debearding will help to get the seed through the seeders.

Seedings may be made into existing grass sods, but the grass must be destroyed. Roundup will remove

most grasses when applied according to label instructions. Atrazine also may be used for seeding big bluestem into a grass sod. A no-till drill is needed to place seeds into soil surface for good soil-seed contact.

Fertilization

Warm-season perennial grasses prefer fertile soils but grow well in moderate fertility conditions. Warm-season perennials do not respond to nitrogen fertilization as much as cool-season perennials. Warm-season perennial grasses use minerals and moisture more efficiently than cool-season perennial grasses.

For establishment, fertilize with 30 to 40 pounds of nitrogen, 24 to 30 pounds of phosphate, and 40 to 60 pounds of potash per acre.

For pasture or hay production of established stands, fertilize with 100 to 120 pounds of nitrogen, 50 to 60 pounds of phosphate, and 100 to 120 pounds of potash per acre.

Chapter 9.
Seed Production

Seed production of forage legumes

Illinois is an important producer of red clover seed, but very little seed is produced of other forage legumes. Red clover seed yields vary widely from year to year. Warm, dry summers favor seed production. In part, low yields are caused by inadequate pollination by bees. Only during the clover's second growth period do honey bees visit red clover in numbers high enough to pollinate for high seed yields while they collect pollen and nectar. In Urbana, studies showed that honey bees collected 54 to 99 percent of their daily pollen intake from red clover between July 12 and August 3.

Red clover

Bumblebees also pollinate red clover but are not reliable pollinators because they are not always present in sufficient numbers. The presence of honey bees in the vicinity of red clover fields can be assured by placing hives in or around red clover seed production fields and avoiding use of insecticides that are highly toxic to bees within a mile radius of the red clover seed production fields. Insecticides commonly used on forage crops that are highly toxic to bees include carbaryl, carbofuran, permethrin, dimethoate, phosmet, chlorpyrifos, malathion, and methyl parathion.

To produce red clover seed, use the second growth period crop and at least two colonies of honey bees per acre within or beside the field. On large fields, place the hives in two or more groups. Do not rely on bees present in the neighborhood, because pollination and seed set decrease rapidly as distance between the hives and the crop becomes greater than 800 feet. Bring a sufficient number of hives to the field as soon as it comes into bloom. When all factors for seed production are favorable, proper pollination of red clover by honey bees has the potential of doubling or tripling seed yields.

Sweet clover

White and yellow sweet clovers are highly attractive to bees and other insects. Still, probably because of the large number of blossoms, their seed yields increase when colonies of honey bees are placed nearby. Yields up to 1,400 pounds per acre have been produced in the Midwest when using six colonies of bees per acre. One or two hives per acre will give reasonably good pollination.

Crownvetch

Crownvetch does not attract bees and requires special techniques to produce a commercial crop of seed. Best yields have been obtained by bringing strong, new hives of bees to the fields every 8 to 10 days. Instead of such special provisions, one or more hives of honey bees per acre of crownvetch are of value.

Lespedeza

The effects of insect pollination on annual lespedeza, such as Korean, have not been investigated; but the perennial lespedezas require insect pollination to produce a crop of seed, and honey bees can be used.

Other legumes

Many legumes grown in Illinois for pasture or for purposes other than seed production are visited by honey bees and other bee pollinators. Alfalfa and birdsfoot trefoil — as well as alsike, white, and ladino clovers — all provide some pollen and nectar and, in turn, are pollinated to varying degrees.

During their bloom in July and August, soybeans are visited by honey bees. Soybeans are a major source of honey in the state. In tests at Urbana, honey bee visits to soybeans did not increase seed yield over that of plants caged to exclude bees. Other studies have

indicated that some varieties increase yields as a result of increasing honey bee visits during flowering.

Plant Variety Protection Act

The Plant Variety Protection Act, passed by Congress in 1970, was amended September 1994. The amendment strengthens plant breeder protection of the original Act. The original Act restricted the sale of protected varieties, permitting use of seeds grown from a protected variety by the grower but with a farmer exemption. The farmer exemption permitted sales of protected varieties as "variety not stated" by a farmer to neighboring farmers. Increasing infringements of the intent of this provision resulted in the recent amendment which removes the farmer exemption from the Act. The sale of a protected variety is unlawful without knowledge and consent of the originator of the variety. The Plant Variety Protection Act provides the inventor or owner of a new variety of certain seed-propagated crops the right to exclude others from selling, offering for sale, reproducing, exporting, or using the variety to produce a hybrid, different variety, or blend.

These rights are not automatic. The owner must apply for a certificate of protection. If the owner does not choose to protect the variety, it is public property and anyone may legally reproduce it and sell the seed.

Many varieties of the self-pollinated crops commonly grown in Illinois — such as soybeans and wheat — that were developed by private industry since 1970 are protected varieties. Many varieties developed at state experiment stations are also protected.

Farmers who purchase a protected variety may use their production for seed on their own farm or market it as grain, but are not permitted to sell their production as seed without consent of the holder of the Plant Variety Protection Certificate.

Under the provisions of the Act, the owner may stipulate that the variety be sold by variety name only as a class of certified seed. Seeds of a certified variety are produced according to the standards and procedures of the Association of Official Seed Certifying Agencies, such as an official seed certification agency in the United States or Canada. In Illinois, this is the Illinois Crop Improvement Association. Selling uncertified seed by variety name of any of those varieties protected in this manner is a violation of seed certification rules, the Federal Seed Act, and the State Seed Law. Violators are subject to prosecution.

If the owner of a protected variety does not choose the certified seed provision of the Act, a farmer whose primary occupation is producing food or feed may not sell this production as seed without permission of the owner of the Plant Variety Protection Certificate. Any advertising of the sale of the seed of a protected variety — including farm sale bills — usually is considered an infringement of the rights of the owner (the variety developer or agent). Therefore, any person who desires to sell the uncertified seed of a protected variety must also obtain permission from the variety owner. Violators are subject to civil lawsuits.

The container in which seed of a protected variety is sold should carry a label identifying the seed as that of a protected variety. All seeds offered for sale in Illinois must be labeled according to the Illinois Seed Law. Requirements for labeling vary among the crop seeds. For current information, consult an Illinois Seed Law publication, available from the Illinois Department of Agriculture.

Plant variety protection has greatly benefited U.S. agriculture. Many improved varieties of various crops have been developed that would not have been developed without this protection. Farmers should not be reluctant to use "protected varieties" since many of these will be top performers, but they must be aware of the limitation of use of these crops for seed purposes.

Chapter 10. Water Quality

The protection of water quality is an important part of any crop production system. Illinois farmers have a great stake in protecting drinking water quality because they often consume the water that lies directly under their farming operation. Their domestic water wells are often in proximity to agricultural operations or fields and, therefore, must be safeguarded against contamination. The great majority of crop protection chemicals never reach groundwater. In Illinois, favorable soil and geologic conditions help degrade or retard movement of pesticides. Vulnerable site conditions are found in some parts of Illinois, however. In these areas (described in detail later) appropriate chemical selection and management decisions need to be made to ensure good water quality.

Drinking-water standards

New federal drinking-water standards for 18 pesticides and pesticide break-down products went into effect on July 30, 1992. This regulation will require public-water-supply monitoring for these compounds at least four times annually. The most commonly used herbicides on the list are atrazine and alachlor. Many other commonly used herbicides are currently unregulated but will be monitored in the drinking-water samples. Initially, only surface-water supplies (lakes, reservoirs) will be monitored, and groundwater sources will be phased in over the next three years.

Compliance with the federal standards will be based on the average of the samples taken consecutively over a 1-year period. For example, atrazine has a standard of 3 parts per billion (ppb), so if the sum of four quarterly samples is equal to 12 ppb or more, the water is out of compliance. A single detection of over 12 ppb would therefore immediately put a water supply out of compliance.

If standards are exceeded, water customers will be notified by local media and subsequently on their water bill. If a water source is in violation, water blending with an uncontaminated supply or extensive decontamination treatment will be required. The additional water-treatment expense can be prohibitive to small communities; this underlines the importance of agricultural management practices that reduce the entry of herbicides into the aquatic system.

Illinois water quality results

The Illinois Environmental Protection Agency has analyzed finished drinking water at 129 surface-water supplies in 1991 and 1992. The study provides a look at the potential for noncompliant water supplies in the coming years (Table 10.01). About 13 percent of the surface water samples exceeded the 3-ppb drinking-water standard for atrazine. Detections of atrazine exceeded 50 percent for both years of the study. The drop in detections in 1992 may be related to a drier spring that resulted in less cropland runoff directly following herbicide application. Trifluralin is a herbicide that is tightly held to soil particles. Trifluralin's

Table 10.01. Herbicide Detections in Selected Community Water Supplies in Illinois

Pesticide	Percent supply detections		Maximum concentration	Minimum concentration detected	Percent exceeding maximum contaminant level (MCL)
	1991	1992			
			ug/1		
Atrazine	78	55	13.0	.03	13
Alachlor	52	17	2.0	.02	<1
Metolachlor	49	30	30.0	.02	
Trifluralin	23	5	0.36	.02	
Cyanazine	11	38	16.0	.06	

SOURCE: Illinois EPA.

presence in 23 percent of the samples in 1991 suggests that erosion of soil with attached herbicide may be responsible for some of the detections.

A statewide study of rural private water supplies involving 337 wells was conducted cooperatively by the Illinois Department of Agriculture, the UI Cooperative Extension Service, and the state Geological Survey. The study was completed in 1992 (Table 10.02). Results of the study offer the first statistically valid estimate of the condition of well water in Illinois. About 12 percent of the 360,000 rural private wells in the state contained detectable concentrations of at least one herbicide, and 10.5 percent of the wells had nitrate nitrogen above the drinking-water standard of 10 ppm. Preliminary interpretation of the data suggests that shallow wells and dug wells were more likely to be contaminated than deep-drilled wells. Wells drawing water from aquifers within 20 feet of land surface were more likely to contain high levels of nitrate. The 2.1 percent of wells containing pesticide concentrations above the drinking-water standards were fully accounted for by three compounds: alachlor (Lasso), dieldrin (a pesticide whose registration has been canceled), and heptachlor epoxide (a degradation product of a discontinued insecticide).

No interpretation of contamination source is possible with the study, so it is impossible to determine whether the compounds were point-source (spill) or non-point-source (leached into water from regular farm practices) in origin. Pesticides detected in greater than 1 percent of the wells include: aciflurofen (1.4 percent, Blazer), atrazine (2.1 percent, AAtrex); bentazon (1.4 percent, Basagran); dieldrin (1.6 percent); dinoseb (3.7 percent, Dyanap); and prometon (1.2 percent, Pramitol). The following pesticides were detected in 0.1 to 1.0 percent of the wells: alachlor (0.7 percent, Lasso); aldrin (0.3 percent); bromacil (0.3 percent, Hyvar-X); chloramben (0.2 percent, Amiben); 2,4-D (0.1 percent); endrin (0.8 percent); metolachlor (0.3 percent, Dual); metribuzin (0.1 percent, Lexone, Sencor); simazine (0.2 percent, Princep); and trifluralin (1.0 percent, Treflan). Atrazine was not found in any well at concentrations above the drinking-water standard of 3 ppb. Additionally, 19 of the pesticides (or their breakdown products) were not detected in any of the wells. These include: butylate (Sutan +); cyanazine (Bladex); 2,4-DB; dicamba (Banvel); and EPTC (Eptam).

Table 10.02. Statewide Estimates for Percent and Number of Rural, Private Wells Containing Pesticides and Nitrate

	Estimated percentage of wells	Confidence interval	Estimated number of wells in Illinois
Pesticides	12.1	7.5 to 16.7	43,600
Pesticides (>MCL/HAL)	2.1	0.6 to 3.6	7,560
Nitrate nitrogen (>10 ppm)	10.5	6.7 to 14.3	37,800

NOTE: MCL = maximum contaminant level; HAL = health advisory level; ppm = parts per million.

Results from surface- and well-water samples suggest that atrazine is the most likely herbicide to appear in surface water but does not appear to be widely found in well water at levels above drinking-water standards. Alachlor and several discontinued insecticides are the predominant organic pesticide contaminants in rural well water. Nitrate nitrogen contamination is often associated with shallow wells and surface water and may be an indication of movement of fertilizers, manures, and other wastes into these water supplies. The greatest challenge facing Illinois producers may be to keep herbicides out of the surface-water supplies. Management practices that reduce run-off may be helpful in this regard.

In other studies, the highest levels of detection are often from wells that are in proximity to chemical handling sites, or wells that are known to have been contaminated by an accidental point source introduction of the chemical directly to the well, such as back-siphoning.

Protection of groundwater drinking sources is a critical and achievable task that can be accomplished by (1) preventing point source contamination of the well; (2) evaluating the groundwater contamination susceptibility as determined by soil and geologic conditions and the water management system; (3) selecting appropriate chemicals and chemical application strategies; and (4) practicing sound agronomy that uses integrated pest management principles and appropriate yield goals.

Drinking-water contaminants

Many substances in the environment, whether related to industry or agriculture or of natural derivation, have been associated with health problems in humans and livestock. The scope of this chapter does not warrant a full discussion of all pollutants but rather focuses on the contaminants that are associated with agriculture and the rural farmer. The most frequent contaminant of rural wells is coliform bacteria, which are associated with livestock or human waste. These bacteria can enter wells laterally through a septic tank leach field or overland into a wellhead as runoff from livestock impoundments. Nitrate-nitrogen is the second most common substance that can occur in levels exceeding health advisories. Although the presence of nitrates (NO_3) in drinking water is frequently blamed on agriculture, nitrates come from many sources, including septic tanks, livestock waste, and decaying organic matter. Bacteria and nitrates are often the "first to arrive" in a well with high potential for contamination. Together their presence suggests a possible pathway from a contaminating source to the well that has been established.

A variety of herbicides has been detected in trace amounts in potable water supplies. A recently com-

pleted nationwide survey found detectable levels of herbicides in 13 percent of the wells surveyed. Atrazine was detected in 12 percent of the wells surveyed and, therefore, constituted over 90 percent of the total detections. Although the herbicides were detected in a significant percentage of the wells, only 0.11 percent of the wells had herbicide concentrations above the health advisory levels.

Point source prevention

Control of point source contamination is the most important measure a farmer can take to protect a groundwater drinking source. A point source is a well-defined and traceable source of contamination such as a leaking pesticide container, a pesticide spill, or back-siphoning from spray tanks directly into a well. Because point sources involve high concentrations or direct movement of contaminants to the water source, the purifying ability of the soil is bypassed. The following handling practices, based largely on common sense, will minimize the potential for groundwater contamination:

- Never mix chemicals near (within 200 feet of) wells, ditches, streams, or other water sources.
- Prevent back-siphoning of mixed pesticides from the spray tank to the well by always keeping the fill hose above the overflow of the spray tank.
- Store pesticides downslope from well-water sources and a safe distance from both wells and surface waters.
- Triple-rinse pesticide containers, and put rinsate back into the spray tank to make up the final spray mixture.
- Avoid introducing pesticides or fertilizers into sinkholes or abandoned wells. Lateral movement of contaminants in the groundwater to a drinking-water well may be more rapid than vertical movement through the soil.
- Seal abandoned wells to prevent connection between agricultural practices and the groundwater.

Groundwater vulnerability

Site characteristics, including the soil and geologic properties, water table depth, and depth of the well, will determine the potential of nonpoint contamination of the groundwater. Nonpoint sources of contamination are difficult to pinpoint, originate from a variety of sources, and are affected by many processes. Contaminants moving into groundwater from routine agricultural use are an example of a nonpoint source. Producers applying pesticides in vulnerable areas should pay strict attention to chemical selection and management practices.

Soil characteristics

Water-holding capacity, permeability, and organic-matter content are important soil properties that determine a soil's ability to detain surface-applied pesticides in the crop root zone. Fine-textured, dark prairie soils have large water-holding capacities, low permeabilities, and large organic matter contents, all attributes that reduce pesticide leaching due to reduced water flow or increased binding of pesticides. The forest soils that dominate the landscape in western and southern Illinois are slightly lower in organic matter and, therefore, may be less effective at binding pesticides.

The most vulnerable soils for groundwater contamination are the sandy soils that lie along the major river valleys of Illinois. Sandy soils are highly permeable, have low organic-matter contents, and often are irrigated. All of these factors represent increased risks to groundwater quality. Extra precautions in chemical selection and application method should be taken in these vulnerable soils. Irrigators in particular should pay attention to groundwater advisory warnings that restrict the use of some herbicides on sandy soils.

Geology

The geologic strata beneath a farming operation may be important in determining the risk of nonpoint contamination. In Illinois the most hazardous geology for groundwater pollution is the karst or limestone region that occurs along the margins of the Mississippi River and in the northwestern part of the state. Sinkholes and fractures that occur in the bedrock in these areas may extend to the soil surface, providing access for runoff directly to the groundwater. Water moving into these access points bypasses the natural treatment that is provided by percolation through soil. Karst areas should be farmed carefully with due attention to buffer zones around sinkholes to prevent runoff entry to the groundwater. Agronomic practices that minimize runoff are effective ways to reduce the potential for pesticide movement to the groundwater.

Groundwater and well depths

Deep aquifers that lie under impermeable geologic formations are the most protected from contamination by surface activities. Shallow water-table aquifers are more vulnerable to contamination because of their proximity to the surface. Shallow dug wells in water-table or shallow aquifers are also more vulnerable because of typically inadequate wellhead protection.

Surface water contamination

Although groundwater protection receives the majority of media attention, surface water quality is generally at greater risk. Surface waters have a greater capacity for breaking down pesticides, because biological breakdown processes operate at a faster rate than in groundwater. A recent survey of surface waters in Illinois by the U.S. Geological Survey found detectable herbicide levels in 90 percent of the samples taken in

May and June of 1989. Control of surface water contamination is best achieved by controlling runoff movement of water and sediment. Soil conservation practices and prudent use of buffer strips near stream banks generally reduce the probability of surface water contamination.

Management practices

Many effective management practices outlined in other sections of this handbook have been recommended with due consideration to water quality. Management is most critical in areas that are the most vulnerable to contamination.

Nutrient management

Soil testing is a basic foundation for fertilizer recommendations. Testing manures for nutrient content allows accurate crediting for fertilizer replacement. A sound nitrogen management program for grain crops that emphasizes appropriate yield goals and credit for prior legumes will optimize the amount of fertilizer nitrogen introduced to the field. Splitting nitrogen applications on sandy irrigated soils is wise because it reduces the chances for excessive leaching that might occur if a single nitrogen application is used.

Integrated pest management

It is generally assumed that reduced pesticide use results in a reduced probability of groundwater contamination. The use of integrated pest management strategies reduces unnecessary use of pesticides. Two examples are the recommended practice of crop rotation that reduces the need for corn rootworm insecticides in continuous corn, and the use of crop rotation and tolerant varieties to control plant diseases.

Conservation tillage

Reducing tillage and retaining crop residues on the soil surface limits the runoff and overland flow that carries pesticides and nutrients out of the field. The effect of conservation tillage and no-till on groundwater quality is controversial and the subject of much research. Reduction of runoff and erosion is accomplished by increasing infiltration of water. Increased infiltration, particularly through earthworm-formed macropores, offers a transport system to the subsoil that soil-applied pesticides can follow. Conversely, the macropores are not the primary routes of water flow unless heavy rainfall or flooding occurs and allows rapid movement of "clean" rainwater past the soil layers that contain pesticides. Conservation tillage methods are most important in controlling soil erosion on sloping land. Adopting more severe tillage to protect groundwater quality is not warranted based on our current knowledge.

Cover crops

A cover crop such as a small grain or legume may provide water quality benefits from several standpoints. The effectiveness of cover crops in controlling erosion is well documented, and controlling erosion is an important component of surface water quality protection. Small-grain cover crops have shown some efficiency at retrieving residual nitrogen from the soil following fertilized corn or vegetable crops. This feature may be important on sandy irrigated soils where winter rainfall leaches much of the residual nitrogen.

Legumes may provide a source of nitrogen to subsequent crops. Refer to the chapter on cover crops in this handbook for further information.

Chemical properties and selection

The selection of agricultural chemicals is most critical for producers on vulnerable soils and geologic sites. Herbicide selection is a complex task that must take into account the crop, tillage system, target species, and a host of other variables. Chemical properties of the herbicide are important to consider when evaluating their potential to leach to the groundwater. The three most important characteristics of a pesticide that influence leaching potential are solubility in water, ability to bind with the soil (adsorption), and the rate at which it breaks down in the soil. High solubility (dissolves readily), low binding ability, and slow breakdown all increase a pesticide's ability to move to the groundwater. Among the frequently used herbicides that have a greater potential to leach and are labeled with groundwater advisories are those that contain alachlor, atrazine, clopyralid, cyanazine, metribuzin, metolachlor, or simazine (Table 10.03).

Table 10.03. Herbicide and Herbicide Premixes with Groundwater Advisories

Trade name	Common (generic) name
AAtrex, Atrazine	atrazine
Bicep	metolachlor + atrazine
Bladex	cyanazine
Bronco	alachlor + glyphosate
Buctril/atrazine	bromoxynil + atrazine
Bullet	alachlor + atrazine
Cannon	alachlor + trifluralin
Canopy	metribuzin + chlorimuron
Dual	metolachlor
Extrazine	cyanazine + atrazine
Freedom	alachlor + trifluralin
Laddok	bentazon + atrazine
Lariat	alachlor + atrazine
Lasso EC, MT*	alachlor
Lexone	metribuzin
Marksman	dicamba + atrazine
Preview	metribuzin + chlorimuron
Princep, Simazine	simazine
Salute	metribuzin + trifluralin
Sencor	metribuzin
Stinger	clopyralid
Sutazine	butylate + atrazine
Turbo	metribuzin + metolachlor

* Lasso MT has shown reduced leaching tendency in initial experiments.

Precautions for irrigators

Chemigation refers to the application of fertilizers and pesticides through an irrigation system and is a management tool that has benefits and potential drawbacks for groundwater protection. The greatest benefit of chemigation is for fertigation, which is the application of fertilizers, particularly nitrogen, through the irrigation system. Nitrogen application can be more carefully spread out in the vegetative growth period of grain crops, thereby minimizing the susceptibility of leaching.

Chemigation systems should be equipped with back-flow prevention devices. These greatly reduce the threat of back-siphoning undiluted chemicals into the irrigation well. Back-flow prevention devices will likely become mandatory on irrigation systems by 1994 but should already be on every irrigation system that injects chemicals. Reputable irrigation dealers do not sell irrigation systems without this important feature.

Well water testing

The most important step in well water testing is to contact the local health department and determine the procedure for sampling and submitting water for nitrate and bacteria determinations. The service is provided at no cost or a nominal fee in most counties. The presence of coliform bacteria with or without elevated nitrates is a sign that a well is contaminated by runoff or a septic system. Faulty well construction or improper wellhead protection is a major cause of contamination. Pesticide testing is expensive and requires sensitive analytical equipment. Several private water testing laboratories, certified by the Illinois Environmental Protection Agency, will perform water analyses for citizens. Contact a local Extension adviser for information on nearby laboratories.

Chapter 11.

Soil Testing and Fertility

Soil testing

Soil testing is the single most important guide to the profitable application of fertilizer and lime. When soil test results are combined with information about the nutrients that are available to the various crops from the soil profile (Figure 11.13 and Figure 11.15, pages 83, 84), the farmer has a reliable basis for planning the fertility program on each field.

Traditionally, soil testing has been used to decide how much lime and fertilizer to apply. Today, with increased emphasis on the environment, soil tests are also a logical tool to determine areas where adequate or excessive fertilization has taken place. In addition, soil tests are used to monitor the impact of past fertility practices on changes in nutrient status of the field. In order to accomplish this, one must (1) collect samples to the proper depth; (2) collect an adequate number of samples per unit of land area; (3) collect samples from precisely the same areas of the field that were sampled in the past; and (4) collect samples at the proper time.

Depth of sampling. The proper depth of sampling for pH, P, and K is 7 inches. For fields in which reduced tillage systems have been used, proper sampling depth is especially important, as these systems results in less thorough mixing of lime and fertilizer than does a tillage system that includes a moldboard plow. This stratification of nutrients has not adversely affected crop yield, but misleading soil test results may be obtained if samples are not taken to the proper depth.

Under reduced tillage systems, it is of importance to monitor surface soil pH by collecting samples to a depth of 2 inches from at least 3 areas in a 40-acre field. These areas should represent the low, intermediate, and high ground of the field. If surface soil pH is either too high or too low, the efficacy of some herbicides and other chemical reactions may be affected.

Number of samples per unit of land area. The number of soil samples from a field is a compromise between what should be done (information) and what can be done (cost). Sampling at the rate of one composite from each 2½-acre area (Figure 11.01) is suggested.

Field sampling studies show large differences of soil test levels in short distances in some fields. If one has the capability of utilizing computerized spreading techniques and suspects large variations in test values over a short distance, research has shown that collection of one sample from each 1.1-acre area (Figure 11.01) will provide a better representation of the actual field variability. The increased sampling intensity will increase cost of the base information but allows for more complete utilization of technology in mapping soil fertility patterns in the field and more appropriate fertilizer application rates.

Precise sample location. Since soil test results may vary markedly in short distances, it is important to collect samples from precisely the same points each time the field is tested. Following this suggestion will reduce the variation often observed between sampling times. Identification of sample locations may be done by using global positioning system (GPS) equipment or by accurately measuring the sample points with devices such as a measuring wheel. Once the sample points have been identified, collect and composite five soil core samples 1 inch in diameter to a 7-inch depth.

How to sample. A soil tube is the best implement to use for taking soil samples, but an auger or spade also can be used (Figure 11.02). One composite sample from every 2½ acres is suggested. Five soil cores taken with a tube will give a satisfactory composite sample of about 1 to 2 cups in size.

The most common mistake is taking too few samples to represent the fields adequately. Taking shortcuts in sampling may produce unreliable results and lead to higher fertilizer costs, lower returns, or both.

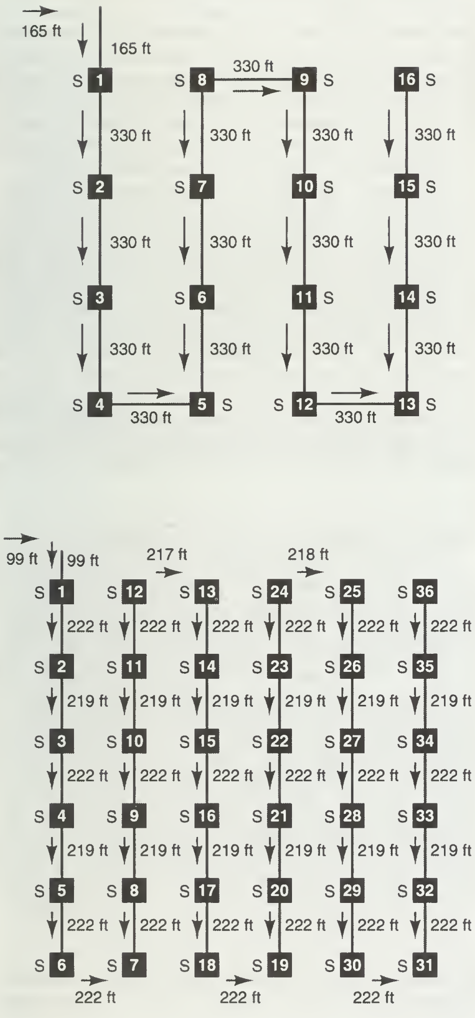


Figure 11.01. Directions for collecting soil samples from a 40-acre field.
NOTE: The upper diagram represents one sample per 2.5 acres. The lower diagram which represents 1 sample per 1.1 acre is suggested for those individuals that have the capability of utilizing computerized spreading techniques on fields that are suspected of having large variation in test values over short distances. In both cases, each sample should consist of 5 soil cores, 1 inch in diameter, collected to a 7-inch depth from within a 10-foot radius around each point.

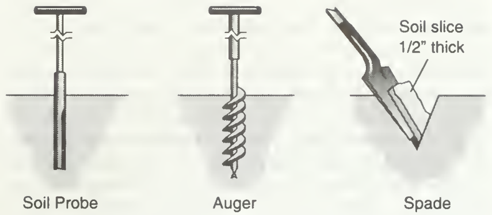


Figure 11.02. How to take soil samples with an auger, soil probe, and spade.

When to sample. Sampling every 4 years is strongly suggested. To improve the consistency of results, it is suggested that samples be collected at the same time of year. Sampling within a few months of lime or fertilizer treatment can be expected to be more variable than after a year..

Late summer and fall are the best seasons for collecting soil samples from the field because potassium test results are most reliable during these times. The K soil test tends to be cyclic, with low test levels in late summer and early fall and high test levels in late January and early February.

Where to have soil tested. Illinois has about 40 commercial soil-testing services. Your local Extension office or fertilizer dealer can provide advice about availability of soil testing in your area.

Information to accompany soil samples. The best fertilizer recommendations are those based on both soil test results and a knowledge of the field conditions that will affect nutrient availability. Because the person making the recommendation does not know the conditions in each field, it is important to provide adequate information with each sample.

This information includes cropping intentions for the next 4 years; name of the soil type, or if not known, then the nature of the soil (clay, silty, or sandy; light or dark color; level or hilly; eroded; well drained or wet; tiled or not; deep or shallow); fertilizer used (amount and grade); lime applied in the past 2 years; and proven yields or yield goals for all proposed crops.

What tests to have made. Soil fertility problems in Illinois are largely associated with acidity, phosphorus, potassium, and nitrogen. Recommended soil tests for making decisions about lime and fertilizer use are as follows: water pH test, which will show soil reaction as pH units; Bray P_1 test for plant-available soil phosphorus, which will commonly be reported as pounds of phosphorus per acre (elemental basis); and the potassium (K) test, which will commonly be reported as pounds of potassium per acre (elemental basis). Guides for interpreting these tests are included in this section. An organic-matter test made by some laboratories is particularly useful in selecting the proper rate of herbicide and agricultural limestone.

Because nitrogen (N) can change forms or be lost

from the soil, the use of soil testing to determine nitrogen fertilizer needs for Illinois field crops is not recommended in the same sense as testing for the need for lime, phosphorus, or potassium fertilizer. Testing the soil to predict the need for nitrogen fertilizer is complicated by the fact that nitrogen availability — both the release from soil organic matter and the loss by leaching and denitrification — is regulated by unpredictable climatic conditions. Under excessively wet conditions, both soil and fertilizer nitrogen may be lost by denitrification or leaching. Under dry conditions, the amount of nitrogen released from organic matter is low, but under ideal moisture conditions, it is high. Use of the organic-matter test as a nitrogen soil test, however, may be misleading and result in underfertilization.

Scientists in Vermont and Wisconsin have identified nitrogen soil tests that work well under their conditions. Specifics of the tests, along with an evaluation of their potential and limitations for Illinois, are discussed in the nitrogen section of this chapter. Guides for planning nitrogen fertilizer use are also provided.

Tests are available for most of the secondary nutrients and micronutrients, but interpretation of these tests is less reliable than the interpretation of tests for lime, phosphorus, or potassium. Complete field history and soil information are especially important in interpreting the results. Even though these tests are less reliable, they may be useful in two ways:

1. *Troubleshooting.* Diagnosing symptoms of abnormal growth. Paired samples representing areas of good and poor growth are needed for analyses.
2. *"Hidden-hunger checkup."* Identifying deficiencies before symptoms appear. Soil tests are of little value in indicating marginal levels of secondary nutrients and micronutrients when crop growth is apparently normal. For this purpose, plant analysis may yield more information.

Soil test ratings (given in Table 11.01) have been developed to put into perspective the reliability, usefulness, and cost effectiveness of soil tests as a basis for planning a soil fertility and liming program for Illinois field crops. These subjective ratings are on a scale from 0 to 100, for which a score of 100 is deemed very reliable, useful, and cost effective, and a score of zero is deemed of little value. Additional research will undoubtedly improve some test ratings.

Interpretation of soil tests and formulation of soil treatment program. See page 75 for suggested pH goals and page 90 for phosphorus and potassium information. Formulate a soil treatment program by preparing field soil test maps to observe areas of similar soil test level that will benefit from similar treatment. Areas with differences in soil test pH of 0.2 unit, P (phosphorus) test of 10, and K (potassium) test of 30 are reasonable to recognize for separate treatment.

What if the soil test is variable? There may be a large variation among tests on a field, and the reason for it and, more important, what to do about it may not be obvious. *First* look at the pattern of the tests over the field. *If there is a definite pattern* of high tests in one part and low in another, check to see whether there is a difference in soil type. *Second,* try to recall whether the field was farmed as separate fields at some time in the recent past. *Third,* check soil test records for this field from previous tests or, if there are no records, try to remember whether the different areas were limed or fertilized differently at some time during the past 5 to 10 years. Whether or not the explanation for large differences in tests is found, split the field and apply basic treatments of lime and fertilizer according to indicated deficiencies.

If there is no consistent pattern of high and low tests, choose between using the lowest tests or an average of the tests as a guide to the amount to apply. If no explanation for large differences in tests is found, consider taking a new set of samples from the field.

Cation-exchange capacity. Chemical elements exist in solution as cations (positively charged ions) or anions (negatively charged ions). In the soil solution, the plant nutrients hydrogen (H), calcium (Ca), magnesium (Mg), potassium (K), ammonium (NH_4), iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) — as well as nonplant nutrients such as sodium (Na), barium (Ba), and metals of environmental concern such as mercury (Hg), cadmium (Cd), chromium (Cr), and others — exist as cations. Cation-exchange capacity is a measure of the amount of attraction for these chemical elements.

Table 11.01. Ratings of Soil Tests

Soil test	Rating[a]	Soil test	Rating
Water pH	100	Organic matter	75
Salt pH	30	Calcium	40
Buffer pH	30	Magnesium	40
Exchangeable H	10	Cation-exchange capacity	60
Phosphorus	85	Sulfur	40
Potassium	80	Zinc	45
Boron (alfalfa)	60	Manganese (pH > 7.5)	40
Boron (corn and soybeans)	10	Manganese (pH < 7.5)	10
Iron (pH > 7.5)	30	Copper (organic soils)	20
Iron (pH < 7.5)	10	Copper (mineral soils)	5

[a] On a scale of 0 to 100, for which a score of 100 rates the test as very reliable, useful, and cost effective, and a score of zero rates the test as having little value.

In soil, a high cation-exchange capacity is desirable but not necessary for high crop yields, as it is not a direct crop yield determining factor. Cation-exchange capacity in soil arises from negatively charged electrostatic charges in minerals and organic matter. Depending on the amount of clay and humus, soil types have a characteristic amount of cation exchange. Sandy soils will have up to 4 milliequivalent (me) per 100 grams of soil; light-colored silt loam soils will be 8 to 12 me; dark-colored silt loam soils will be 15 to 22 me; and clay soils will have 18 to 30 me.

Cation-exchange capacity facilitates retention of positively charged chemical elements from leaching, yet gives nutrients to a growing plant root by an exchange of hydrogen (H). Farming practices that reduce soil erosion and maintain soil humus favor the maintenance of cation-exchange capacity. The cation-exchange capacity of organic residues is low but increases as the residues convert to humus, which requires from 5 years to centuries.

Plant analyses

Plant analyses can be useful in diagnosing problems, in identifying hidden hunger, and also in determining whether current fertility programs are adequate. For example, they often provide more reliable measures of micronutrient and secondary nutrient problems than do soil tests.

How to sample. When making a plant analysis to diagnose a problem, select paired samples of comparable plant parts representing the abnormal and normal plants. Abnormal plants selected should represent the first stages of a problem.

When using the technique to diagnose hidden hunger in corn, sample several of the leaves opposite and below the ear at early tassel time. For soybeans, sample the most recent fully developed leaves and petioles at early podding. Samples taken later will not indicate the nutritional status of the plant. After collecting the samples, deliver them immediately to the laboratory. They should be air-dried if they cannot be delivered immediately or if they are going to be shipped to a laboratory.

Environmental factors may complicate the interpretation of plant analysis data. The more information concerning a particular field, the more reliable the interpretation will be. Suggested critical nutrient levels are provided in Table 11.02. Lower levels may indicate a nutrient deficiency.

Fertilizer management related to tillage systems

Fertilizer management will be affected by tillage systems because immobile materials such as limestone, phosphorus, and potassium move slowly in most soils unless they are physically mixed by tillage operations. Such "stratification" of nutrients, with higher concentrations developing near the surface, has been well documented in a number of studies during the past 30 years but has not been shown to reduce yields of corn or soybeans in Illinois. Limited research indicates that plants develop more roots near the soil surface in conservation-tillage systems, apparently due to both the improved moisture conditions caused by the surface mulch of crop residues and the higher levels of available nutrients.

Soil tests are important for phosphorus, potassium, and limestone management under any tillage system. Consult the section above titled "How to sample," and make sure the samples are taken from the full 7-inch depth. If either limestone (which raises pH) or nitrogen fertilizer (which lowers pH) is applied to the surface and not incorporated with tillage, pH tests of the upper 2 inches of soil are needed to aid in the management of some herbicides.

See guidelines for adjusting limestone application rates under different tillage systems. For any tillage system, the rate of application information contained in the section on "Phosphorus and potassium" is valid.

Nitrogen fertilizer management may be affected to a limited extent by changing tillage systems. The information contained in the section on "Nitrogen" will be valid in all tillage systems, with only the following exceptions:

- Where crop residue is present, a coulter may be needed in front of an applicator knife to properly inject anhydrous ammonia or liquid nitrogen fertilizers.
- In no-till systems, where the surface soil may be firm, special care is needed to make sure that the slit left by an ammonia applicator knife is completely closed to prevent nitrogen loss through the escape of gaseous ammonia.
- Because crop residue in reduced-tillage systems may inhibit urea or urea-containing fertilizers from making direct contact with the soil and thus increase the possibility of nitrogen loss through volatilization, these materials should be mechanically incorporated. Urease inhibitors will aid in preventing this loss.
- The higher moisture conditions under a residue mulch may also cause a higher rate of nitrogen loss through denitrification. Judicious management — including time of application and the use of nitrification inhibitors — may help avoid significant denitrification losses.
- A risk of occasional anhydrous ammonia damage to corn seed and seedlings exists in fields with any tillage system, especially when the soil is dry, the ammonia is placed shallow, or corn is planted immediately after ammonia application. Corn in no-till fields seems to be particularly vulnerable to such damage in spring preplant ammonia applications whenever the seed is placed directly over the am-

Table 11.02. Suggested Critical Plant Nutrient Levels

Crop	Plant part	N	P	K	Ca	Mg	S	Zn	Fe	Mn	Cu	B
		percent						*ppm*				
Corn	Leaf opposite and below the ear at tasseling	2.9	0.25	1.90	0.40	0.15	0.15	15	25	15	5	10
Soybeans	Fully developed leaf and petiole at early podding	...	0.25	2.00	0.40	0.25	0.15	15	30	20	5	25

monia band. Keeping the anhydrous ammonia and the corn separated in either distance or time will reduce the potential for this problem.

Starter Fertilizer. Starter fertilizer is more effective than broadcast applications under cool, moist conditions when phosphorus soil test levels are low, irrespective of tillage system. At high soil test levels, starter fertilizer will often result in early growth response on conventional tillage systems, but seldom result in increased yield at harvest.

Early season growth of no-till corn is frequently less vigorous than conventional tillage. This slower growth is likely the result of cooler soil temperatures and higher soil moisture conditions associated with the high residue mulch. Both of these conditions tend to slow root growth and thus the ability of the plant to absorb nutrients.

While the data are limited, Illinois research has not at this time confirmed the interaction between method and/or time of nitrogen application and starter fertilizer. However, the Illinois research has shown an increase in yield associated with nitrogen and phosphorus in starter fertilizer on corn following corn (Ashton), and on one (Oblong) of three locations on corn following soybeans when soil phosphorus tests were 40 pounds per acre or greater (Table 11.03). In both responding sites, nitrogen appeared to be the primary component causing the response.

Lime

Soil acidity is one of the most serious limitations to crop production. Acidity is created by a removal of bases by harvested crops, leaching, and an acid residual that is left in the soil from nitrogen fertilizers. During the last several years, limestone use has tended to decrease while crop yields and nitrogen fertilizer use have increased markedly (Figure 11.03).

At the present rate of limestone use, no lime is being added to correct the acidity that is created by the removal of bases nor the acidity created in prior years that had not been corrected. A soil test every 4 years is the best way to check on soil acidity levels.

The effect of soil acidity on plant growth. Soil acidity affects plant growth in several ways. Whenever soil pH is low (that is, acidity is high), several situations may exist:

A. The concentration of soluble metals may be toxic. Damage from excess solubility of aluminum and manganese due to soil acidity has been shown in field research.
B. Populations and the activity of the organisms responsible for transformations involving nitrogen, sulfur, and phosphorus may be altered.
C. Calcium may be deficient. This usually occurs only when the cation-exchange capacity of the soil is extremely low.
D. Symbiotic nitrogen fixation in legume crops is impaired greatly. The symbiotic relationship requires a narrower range of soil reaction than does the growth of plants not relying on nitrogen fixation.
E. Acidic soils are poorly aggregated and have poor tilth. This is particularly true for soils that are low in organic matter.
F. The availability of mineral elements to plants may be affected. Figure 11.04 shows the relationship

Table 11.03. Effect of Starter Fertilizer on Grain Yield of No-Till Corn

Starter fertilizer			Location			
			Ashton	Gridley	Pana	Oblong
			Previous crop			
N	P_2O_5	K_2O	corn	soybean	soybean	soybean
lb/acre			Yield bu/acre			
0	0	0	122 E	143A	171A	187 BC
25	0	0	131 BCD	133ABC	175A	194AB
0	30	0	126 DE	130 BC	175A	183 C
25	30	0	142A	128 BC	185A	196A
0	0	20	128 CDE	124 BC	171A	184 C
25	0	20	136ABC	131 BC	175A	193AB
0	30	20	126 DE	134AB	170A	187 BC
25	30	20	138AB	123 C	178A	196A

NOTE: Numbers followed by the same letter within a column are not significantly different.

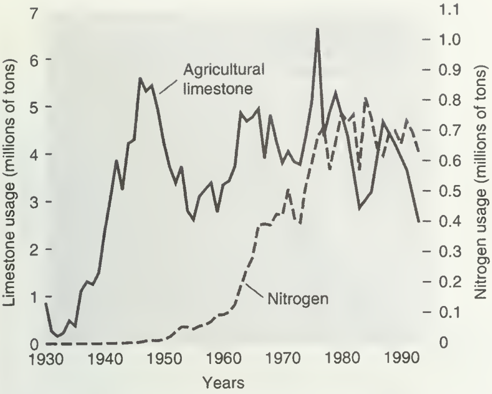


Figure 11.03. Use of agricultural lime and commercial nitrogen fertilizer, 1930–1989.

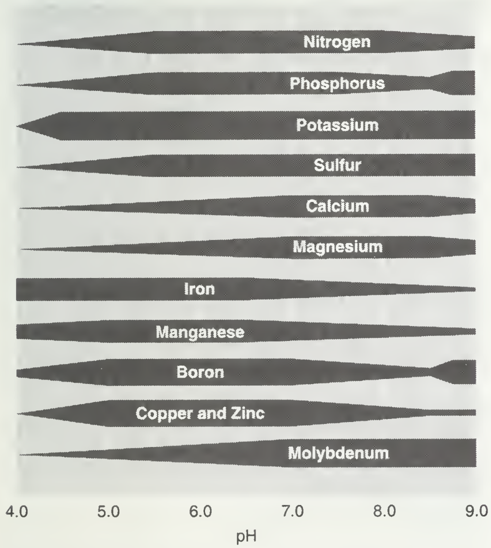


Figure 11.04. Available nutrients in relation to pH.

between soil pH and nutrient availability. The wider the dark bar, the greater the nutrient availability. For example, the availability of phosphorus is greatest in the pH range between 6.0 and 7.5, dropping off below 6.0. Because the availability of molybdenum is increased greatly as soil acidity is decreased, molybdenum deficiencies usually can be corrected by liming.

Suggested pH goals. For cash-grain systems (no alfalfa or clover), maintaining a pH of at least 6.0 is a realistic goal. If the soil test shows that the pH is 6.0 or less, apply limestone. After the initial investment, it costs little more to maintain a pH at 6.5 than it does at 6.0. The profit over a 10-year period will be little affected because the increased yield will approximately offset the cost of the extra limestone plus interest.

Research indicates that a profitable yield response from raising the pH above 6.5 in cash-grain systems is unlikely.

For cropping systems with alfalfa and clover, aim for a pH of 6.5 or higher unless the soils have a pH of 6.2 or higher without ever being limed. In those soils, neutral soil is just below plow depth; and it will probably not be necessary to apply limestone.

Liming treatments based on soil tests. The limestone requirements in Figure 11.05 assume:

A. A 9-inch plowing depth. If plowing is less than 9 inches, reduce the amount of limestone; if more than 9 inches, increase the lime rate proportionately. In zero-tillage systems, use a 3-inch depth for calculations (one-third the amount suggested for soil moldboard-plowed 9 inches deep).

B. Typical fineness of limestone. Ten percent of the particles are greater than 8-mesh; 30 percent pass an 8-mesh and are held on 30-mesh; 30 percent pass a 30-mesh and are held on 60-mesh; and 30 percent pass a 60-mesh.

C. A calcium carbonate equivalent (total neutralizing power) of 90 percent. The rate of application may be adjusted according to the deviation from 90.

Instructions for using Figure 11.05 are as follows:

1. Use Chart I for grain systems and Chart II for alfalfa, clover, or lespedeza.
2. Decide which classification fits the soil:
   a. Dark-colored silty clays and silty clay loams. (CEC > 24)
   b. Light- and medium-colored silty clays and silty clay loams; dark-colored silt and clay loams. (CEC 15-24)
   c. Light- and medium-colored silt and clay loams; dark- and medium-colored loams; dark-colored sandy loams. (CEC 8-15)
   d. Light-colored loams; light- and medium-colored sandy loams; sands. (CEC < 8)
   e. Muck and peat.

Soil color is related to organic-matter level. Light-colored soils usually have less than 2.5 percent organic matter; medium-colored soils have 2.5 to 4.5 percent organic matter; dark-colored soils have more than 4.5 percent organic matter; sands are excluded.

Limestone quality. Limestone quality is measured by the neutralizing value and the fineness of grind. The neutralizing value of limestone is measured by its calcium carbonate equivalent: the higher this value, the greater the limestone's ability to neutralize soil acidity. Rate of reaction is affected by particle size; the finer that limestone is ground, the faster it will neutralize soil acidity. Relative efficiency factors have been determined for various particle sizes (Table 11.04).

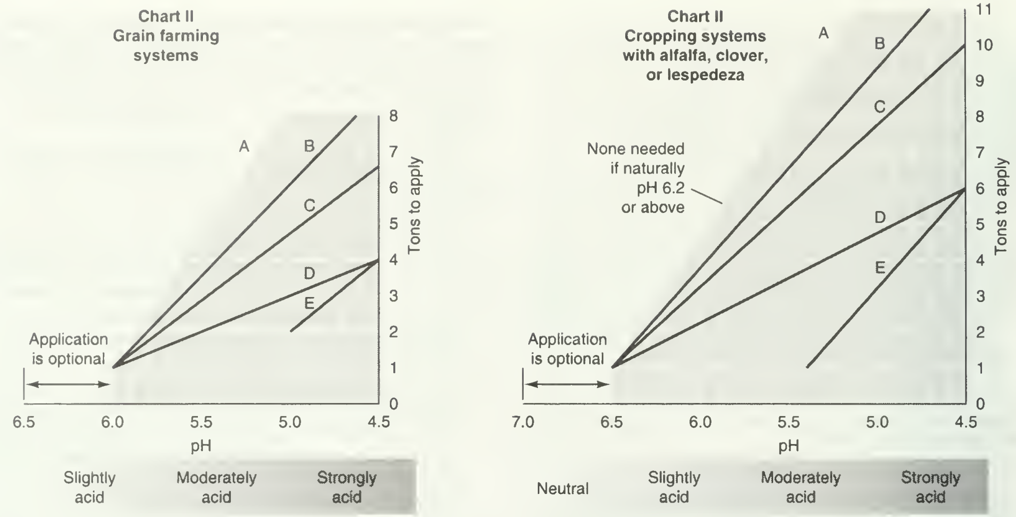


Figure 11.05. Suggested limestone rates based on soil type, pH, cropping systems, and 9-inch depth of tillage.

Worksheet

Evaluation for 1 year after application of lime

		Efficiency factor	
% of particles greater than 8-mesh	= $\frac{\_\_\_\_}{100}$ ×	5	=
% of particles that pass 8-mesh and are held on 30-mesh	= $\frac{\_\_\_\_}{100}$ ×	20	=
% of particles that pass 30-mesh and are held on 60-mesh	= $\frac{\_\_\_\_}{100}$ ×	50	=
% of particles that pass 60-mesh	= $\frac{\_\_\_\_}{100}$ ×	100	=

Total fineness efficiency ______

$$\text{ENV} = \text{total fineness efficiency} \times \frac{\%\ \text{calcium carbonate equivalent}}{100}$$

$$\text{Correction factor} = \frac{\text{ENV of typical limestone (46.35)}}{\text{ENV of sampled limestone (\_\_\_)}}$$

Correction factor × limestone requirement (from Figure 10.5) = ______ tons of sampled limestone needed per acre

Evaluation for 4 years after application of lime

		Efficiency factor	
% of particles greater than 8-mesh	= $\frac{\_\_\_\_}{100}$ ×	15	=
% of particles that pass 8-mesh and are held on 30-mesh	= $\frac{\_\_\_\_}{100}$ ×	45	=
% of particles that pass 30-mesh and are held on 60-mesh	= $\frac{\_\_\_\_}{100}$ ×	100	=
% of particles that pass 60-mesh	= $\frac{\_\_\_\_}{100}$ ×	100	=

Total fineness efficiency ______

$$\text{ENV} = \text{total fineness efficiency} \times \frac{\%\ \text{calcium carbonate equivalent}}{100}$$

$$\text{Correction factor} = \frac{\text{ENV of typical limestone (67.5)}}{\text{ENV of sampled limestone (\_\_\_)}}$$

Correction factor × limestone requirement (from Figure 10.5) = ______ tons of sampled limestone needed per acre

Example from the worksheet

1 Year

$$\frac{13.1\%}{100} \times 5 = 0.65$$

$$\frac{40.4\%}{100} \times 20 = 8.08$$

$$\frac{14.9\%}{100} \times 50 = 7.45$$

$$\frac{31.6\%}{100} \times 100 = 31.60$$

Total fineness efficiency 47.78

$$\text{ENV} = 47.78 \times \frac{86.88}{100} = 41.51$$

$$\frac{46.35}{41.51} \times 3 = 3.35 \text{ tons per acre}$$

4 Years

$$\frac{13.1\%}{100} \times 15 = 1.96$$

$$\frac{40.4\%}{100} \times 45 = 18.18$$

$$\frac{14.9\%}{100} \times 100 = 14.90$$

$$\frac{31.6\%}{100} \times 100 = 31.60$$

Total fineness efficiency 66.64

$$\text{ENV} = 66.64 \times \frac{86.88}{100} = 57.9$$

$$\frac{67.5}{57.9} \times 3 = 3.5 \text{ tons per acre}$$

Table 11.04. Efficiency Factors for Various Limestone Particle Sizes

Particle sizes	Efficiency factor: 1 year after application	4 years after application
Greater than 8-mesh	5	15
8- to 30-mesh	20	45
30- to 60-mesh	50	100
Passing 60-mesh	100	100

The quality of limestone is defined as its effective neutralizing value (ENV). This value can be calculated for any liming material by using the efficiency factors in Table 11.04 and the calcium carbonate equivalent for the limestone in question. The "typical" limestone on which Figure 11.05 is based has an ENV of 46.35 for 1 year and 67.5 for 4 years.

The Illinois Department of Agriculture, in cooperation with the Illinois Department of Transportation, collects and analyzes limestone samples from quarries that wish to participate in the Illinois Voluntary Limestone Program. These analyses, along with the calculated correction factors, are available from the Illinois Department of Agriculture, Division of Plant Industries and Consumer Services, P.O. Box 19281, Springfield, IL 62794-9281, in an annual publication titled *Illinois Voluntary Limestone Program Producer Information.* To calculate the ENV for materials not reported in that publication, obtain the analysis of the material in question from the supplier and use the worksheet provided for making calculations.

As an example, consider a limestone that has a calcium carbonate equivalent of 86.88 percent and a sample that has 13.1 percent of the particles greater than 8-mesh, 40.4 percent that pass 8-mesh and are held on 30-mesh, 14.9 percent that pass 30-mesh and are held on 60-mesh, and 31.6 percent that pass 60-mesh. Assume that 3 tons of typical limestone are needed per acre (according to Figure 11.05).

At rates up to 6 tons per acre, if high initial cost is not a deterrent, then the entire amount may be applied at one time. If cost is a factor and the amount of limestone needed is 6 tons or more per acre, apply it in split applications of about two-thirds the first time and the remainder 3 or 4 years later.

Fluid lime suspensions (liquid lime). These products are obtained by suspending very finely ground limestone in water. Several industrial by-products that have liming properties also are being land-applied as suspensions, either because they are too fine to be spread dry or they are already in suspension. These by-product materials include residue from water treatment plants, cement plant stack dusts, paper mill sludge, and other waste products. These materials may contain as much as 50 percent water. In some cases, a small amount of attapulgite clay is added as a suspending agent.

The chemistry of liquid liming materials is the same as that of dry materials. Research results have confirmed that the rate of reaction and neutralizing power for liquid lime are the same as for dry materials when particle sizes are the same.

Results collected from one research study indicate that application of liquid lime at the rate of material calculated by the following equation is adequate to maintain soil pH for at least a 4-year period at the same level as typical lime.

$$\frac{\text{ENV of typical limestone (use 46.35)}}{\text{100 (fineness efficiency factor)} \times \frac{\text{\% calcium carbonate equivalent, dry matter basis}}{100} \times \frac{\text{\% dry matter}}{100}}$$

$\times$ tons of limestone needed per acre = tons of liquid lime needed per acre

During the first few months after application, the liquid material will provide a more rapid increase in pH than will typical lime, but after that the two materials will provide equivalent pH levels in the soil.

As an example, assume a lime need of 3 tons per acre (based on Figure 11.05) and liquid lime that is 50 percent dry matter and has a calcium carbonate equivalent of 97 percent on a dry matter basis. The rate of liquid lime needed would be calculated as follows:

$$\frac{46.35}{100 \times \frac{97}{100} \times \frac{50}{100}} \times 3 = 2.87 \text{ tons of liquid lime per acre}$$

Lime incorporation. Lime does not react with acidic soil very far from the particle; but special tillage operations to mix lime with soil usually are not necessary in systems that use a moldboard plow. Systems of tillage that use a chisel plow, disk, or field cultivator rather than a moldboard plow, however, may not mix limestone deeper than 4 to 5 inches.

Calcium-magnesium balance in Illinois soils

Soils in northern Illinois usually contain more magnesium than those in central and southern Illinois because of the high magnesium content in the rock from which the soils developed and because northern soils are geologically younger. This relatively high level of magnesium has caused some speculation as to whether the level is too high. Although there have been reports of suggestions that either gypsum or low-magnesium limestone should be applied, no research data has been put forth to justify concern over a too-narrow ratio of calcium to magnesium.

On the other hand, concern is justified over a soil magnesium level that is low — because of its relationship with hypomagnesemia, a prime factor in grass tetany or milk fever in cattle. This concern is more relevant to forage production than to grain production. Very high potassium levels (more than 500 pounds per acre) combined with low-soil magnesium levels contribute to low-magnesium grass forages. Research data to establish critical magnesium levels are very limited. However, levels of soil magnesium less than 60 pounds per acre on sands and 150 pounds per acre on silt loams are regarded as low.

Calcium and magnesium levels of agricultural limestone vary among quarries in the state. Dolomitic limestone (material with an appreciable magnesium content as high as 21.7 percent MgO or 46.5 percent $MgCO_3$) occurs predominantly in the northern three tiers of Illinois counties, in Kankakee County, and in Calhoun County. Limestone occurring in the remainder of the state is predominantly calcitic (high calcium), although it is not uncommon for it to contain 1 to 3 percent $MgCO_3$.

For grain farmers, there are no agronomic reasons to recommend either that farmers in northern Illinois bypass local limestone sources, which are medium to high in magnesium, and pay a premium for low-magnesium limestone from southern Illinois or that farmers in southern Illinois order limestone from northern Illinois quarries because of magnesium content.

For farmers with a livestock program or who produce forages in the claypan and fragipan regions of the south, where soil magnesium levels may be marginal, it is appropriate to use a soil test to verify conditions and to use dolomitic limestone or magnesium fertilization or to add magnesium to the feed.

Nitrogen

About 40 percent of the original nitrogen and organic-matter content has been lost from typical Illinois soils since farming began, by erosion and from increased oxidation of organic matter. Erosion reduces the nitrogen content of soils because the surface soil is richest in nitrogen and this erodes first. Farming practices that improved aeration of the soil, including improved drainage and tillage, have increased the rate of organic matter degradation. Further nitrogen losses occur as a result of denitrification and leaching.

Because harvested crops remove more nitrogen than any other nutrient from Illinois soils, the use of nitrogen fertilizer is necessary if Illinois agriculture is to be competitive in the world market. Low grain prices, along with concern for the environment, make it imperative that all nitrogen fertilizers be used in the most efficient manner possible. Factors that influence efficiency of fertilizer use are discussed in the following sections.

Nitrogen recommendation systems

Nitrogen recommendations in the humid regions of the Corn Belt have been based in large part on expected yield with an adjustment for previous crop and management programs. Although this system has worked well, there are documented reports of near-optimal corn yields with little or no supplemental nitrogen. Such results have encouraged researchers to develop a reliable and practical soil nitrogen test that would give farmers and their advisers the opportunity to identify those conditions where the nitrogen application rate could likely be modified to enhance crop profits without harming the environment.

Total soil nitrogen. Because 5 percent of soil organic matter is nitrogen, some have theorized that organic matter content of a soil could be used as an estimate of the amount of supplemental nitrogen that would be needed for a crop. Attempts to use this procedure have been unsuccessful because mineralization of organic matter varies significantly over time due to variation in available soil moisture. Additionally, soils high in organic matter usually have a higher yield potential due to their ability to provide a better environment for crop growth.

Early spring nitrate nitrogen. This procedure has been used for several years in the more arid parts of the Corn Belt (west of the Missouri River) with rea-

sonable success. It involves the collection of soil samples in 1-foot increments to a 2- to 3-foot depth in early spring for analysis of nitrate nitrogen. Although the use of the information varies somewhat from state to state, the consensus is to reduce the normal nitrogen recommendation by the amount found in the soil profile sampled. Results obtained by scientists in both Wisconsin and Michigan in the late 1980s have found this procedure to work well, but work in Iowa indicated that the procedure did not accurately predict nitrogen needs.

Since samples are collected in early spring, this procedure measures potential for nitrogen carryover from the previous crop. Therefore, it will have the greatest potential for success on continuous corn, especially in fields where adverse growing conditions have limited yields the previous year. Additional work is needed to ascertain the sampling procedure that will best characterize the field conditions, especially when nitrogen has been injected in prior years. When excessive precipitation is received in late spring or early summer, this procedure will not likely be successful because most of the nitrogen that is detected early may be leached or denitrified before the plant has an opportunity to absorb it from the soil.

Late-spring nitrate nitrogen. Success with this procedure was first observed with work in Vermont. Follow-up work in Iowa in the late 1980s also indicated that the procedure accurately characterized nitrogen needs. Soil samples are collected to a 1-foot depth when corn plants are 6 to 12 inches tall and analyzed for nitrate nitrogen. Several university agronomists suggest that no additional nitrogen be applied when soil test levels exceed 26 parts per million (52 pounds per acre) and that full rate be applied if nitrate nitrogen levels are less than 10 parts per million. They suggest proportional adjustments in nitrogen rates when test levels are between 10 and 26 parts per million. To minimize the potential for decreased yield that might be caused by delayed nitrogen application, agronomists at Iowa State University suggest that 50 to 70 percent of the normal nitrogen application be applied preplant. If the fertilizer was broadcast, they suggest collecting 16 to 24 core samples within an area not exceeding 10 acres. If the fields have been fertilized with anhydrous ammonia, they suggest a modified soil test. The modified test can be used under the following conditions: (a) the rate of ammonia application did not exceed 125 pounds of nitrogen per acre; (b) the soil sample is derived from at least 24 cores collected without regard to location of ammonia injection bands; and (c) fertilizer nitrogen recommendations are adjusted to reflect that one-third of the nitrogen applied was not revealed by the soil test.

If sampling is done later in the season, testing provides a measure of the mineralization of organic nitrogen that has occurred and the amount of residual carryover that is still present in the soil. Obvious limitations of this procedure include: (a) its use only on fields that receive sidedress application of nitrogen; (b) the short time available between sampling and the need to apply fertilizer — this could be especially critical in wet years and could result in corn plants becoming too large to use conventional application equipment; and (c) no existing correlation for use of the procedure on fields that have received a banded nitrogen application.

Because none of the nitrogen soil procedures have given adequate crop nitrogen (N) requirement predictions, their use is not encouraged under Illinois conditions. It is suggested that nitrogen rates be determined using the following materials as a guide.

Yield potential

Corn. Proven yield potential is one of the major considerations to use in determining the optimum rate of nitrogen application for corn. These potentials should be established for each field, taking into account the soil type and management level under which the crop will be grown. If yield records are available, use the 5-year average yield as the basis. When figuring the average, eliminate years of abnormally low yields that resulted from drought or other weather-related conditions.

If yield records are not available for a particular field, suggested productivity-index values are given in Illinois Cooperative Extension Service Bulletin 778, *Soils of Illinois.* Yield goals are presented for both basic and high levels of management. For fields that will be under exceptionally high management, a 15 to 20 percent increase in the values given for high levels of management would be reasonable. Annual variations in yield of 20 percent above or below the productivity-index values are common because of variations in weather conditions. However, applying nitrogen fertilizer for yields possible in the most favorable year will not result in maximum net return when averaged over all years.

The University of Illinois Department of Agronomy has conducted research trials designed to determine the optimum nitrogen rate for corn under varying soil and climatic conditions. The results of these experiments show that average economic optimum nitrogen rates varied from 1.22 to 1.32 pounds of nitrogen per bushel of corn produced when nitrogen was applied in the spring (Table 11.05). The lower rate of application (1.22 pounds) would be recommended at a corn-nitrogen price ratio (corn price per bushel to nitrogen price per pound) between 10:1 and 20:1, and the higher rate (1.32 pounds) at a price ratio of 20:1 or greater.

As would be expected, the nitrogen requirement was lower at sites having a corn-soybean rotation than at sites with continuous corn. (See the subsection about rate adjustments on page 83.)

With the exception of Dixon, which was based on limited data, Brownstown and DeKalb had the highest nitrogen requirement per bushel of corn produced. In

Table 11.05. **Economic Optimum Nitrogen Rate Experimentally Determined for Eight Locations as Affected by Corn-Nitrogen Price Ratios**

	Corn-nitrogen price ratio			
	10:1		20:1	
Location and rotation	Optimum yield, bu/acre	Optimum N rate, lb/bu	Optimum yield, bu/acre	Optimum N rate, lb/bu
Brownstown (continuous corn)	83	1.30	86	1.47
Carthage (continuous corn)	144	1.22	147	1.29
DeKalb (continuous corn)	141	1.28	143	1.31
Urbana (continuous corn)	171	1.17	173	1.24
Average of continuous corn		1.24		1.33
Dixon (corn-soybeans)	131	1.37	134	1.58
Hartsburg (corn-soybeans)	156	1.19	157	1.27
Oblong (corn-soybeans)	123	1.11	126	1.23
Toledo (corn-soybeans)	123	1.12	124	1.20
Average of corn-soybeans		1.20		1.32
Average of all locations		1.22		1.32

part, this higher requirement may be the result of the higher denitrification losses that frequently have been observed at Brownstown and DeKalb.

Based on these results, Table 11.06 gives examples of the recommended rate of nitrogen application for selected Illinois soils under a high level of management.

Evaluation of nitrogen recommendation systems for corn. Over a three-year period, experiments were conducted at 77 locations around Illinois to evaluate the potential for using the nitrate nitrogen soil test systems to improve nitrogen recommendations. Use of the nitrate nitrogen soil test systems was compared to use of yield potential, times a factor, minus adjustments for previous crops and legumes. Considering only those locations exhibiting a significant response to applied fertilizer nitrogen, all three systems — those based on yield potential with an adjustment for previous crop or manure application, and those based on yield potential with an adjustment for the amount of nitrate nitrogen observed in the soil at early spring or at pre-sidedress time — gave recommendations that were within 8 pounds of the amount needed for the fields on the average (Table 11.07). Adjustments based on the early spring nitrate nitrogen test resulted in recommendations about 25 pounds less than needed to obtain the most return per acre.

Table 11.06. **Nitrogen Recommendations for Selected Illinois Soils Under High Level of Management**

	Corn-nitrogen price ratio	
Soil type	10:1	20:1
	nitrogen recommendation, lb/acre	
Muscatine silt loam	205	220
Ipava silt loam	200	215
Sable silty clay loam	190	205
Drummer silty clay loam	185	200
Plano silt loam	185	200
Hartsburg silty clay loam	175	190
Fayette silt loam	155	170
Clinton silt loam	155	170
Cowden silt loam	145	160
Cisne silt loam	140	150
Bluford silt loam	125	135
Grantsburg silt loam	115	125
Huey silt loam	80	85

None of the three systems provided accurate recommendations for fields where adverse weather conditions limited yield potential far below expectation and limited yield response to applied nitrogen (Table 11.08). At locations where manure had been applied prior to planting, all three recommendation systems predicted a need for little supplemental fertilization.

Based on results so far, none of the nitrogen soil test procedures now available offer enough improved accuracy or reliability over the yield potential system described earlier to justify their use on Illinois fields. The exception appears to be on fields that have received a broadcast application of manure or other organic nitrogen–containing materials. In those cases, if the nitrate nitrogen test exceeds 25 parts per million at the time the corn is 6 to 12 inches tall, there is no need for additional nitrogen fertilizer.

Soybeans. Based on average Illinois corn and soybean yields from 1990 and 1991 and average nitrogen content of the grain for these two crops, the total nitrogen removed per acre by soybeans was greater than that removed by corn (soybeans, 153 pounds of nitrogen per acre; corn, 90 pounds of nitrogen per acre). Research results from the University of Illinois, however, indicate that when properly nodulated soybeans were grown at the proper soil pH, the symbiotic fixation was equivalent to 63 percent of the nitrogen removed in harvested grain. Thus, the net nitrogen removal by soybeans was less than that of corn (corn, 90; soybeans, 57).

This net removal of nitrogen by soybeans in 1990–91 was equivalent to 27 percent of the amount of

Table 11.07. Relationship Between Experimentally Derived, Economically Optimum Nitrogen Rates and Nitrogen Recommendations from Three Recommendation Systems

Number of locations	Yield goal	Optimum yield	Optimum N rate	Recommendation system PY[a]	PPNT[b]	PSNT[c]
	bushel/acre		lb N/acre			
Responding sites						
44	139	161	138	137	107	130
Nonresponding sites						
33	143	145	0	111	76	113

[a] Proven yield. University of Illinois Department of Agronomy recommendations using proven yield.
[b] Preplant nitrogen test. UI Department of Agronomy recommendations, minus nitrate content in top 2 feet of surface soil in early spring.
[c] Pre-sidedress nitrogen test. Iowa State University Department of Agronomy nitrogen recommendations.

Table 11.08. Relationship Between Experimentally Derived, Economically Optimum Nitrogen Rates and Nitrogen Recommendations from Three Recommendation Systems as Influenced by Manure Application, Environmental Factors, and Previous Crop

Number of locations	Yield goal	Optimum yield	Optimum N rate	Recommendation system PY[a]	PPNT[b]	PSNT[c]
	bushel/acre		lb N/acre			
Manured sites						
9	144	185	0	24	10	36
Drought-affected sites						
8	153	99	0	163	118	128
Forage legume sites						
4	148	164	0	102	74	85

[a] Proven yield. University of Illinois Department of Agronomy recommendations using proven yield.
[b] Preplant nitrogen test. UI Department of Agronomy recommendations, minus nitrate content in top 2 feet of surface soil in early spring.
[c] Pre-sidedress nitrogen test. Iowa State University Department of Agronomy nitrogen recommendations.

fertilizer nitrogen used in Illinois. On the other hand, symbiotic fixation of nitrogen by soybeans in Illinois (438,500 tons of nitrogen) was equivalent to 44 percent of the fertilizer nitrogen used in Illinois.

Even though there is a rather large net nitrogen removal from soil by soybeans (57 pounds of nitrogen per acre), research at the University of Illinois has generally indicated no soybean yield increase caused by either residual nitrogen in the soil or nitrogen fertilizer applied for the soybean crop.

1. *Residual from nitrogen applied to corn (Table 11.09).* Soybean yields at four locations were not increased by residual nitrogen in the soil, even when nitrogen rates as high as 320 pounds per acre had been applied to corn the previous year.
2. *Nitrogen on continuous soybeans (Table 11.10).* After 18 years of continuous soybeans at Hartsburg, yields were unaffected by applications of nitrogen fertilizer.
3. *High rates of added nitrogen (Table 11.11).* Moderate rates of nitrogen were applied to soybeans in the first year of a study at Urbana. Rates were increased in the second year so that the higher rates would furnish more than the total nitrogen needs of soybeans. Yields were not affected by nitrogen in the first year; but with 400 pounds per acre of nitrogen, a tendency toward a yield increase occurred in the second and third years. However, the yield increase

Table 11.09. Soybean Yields at Four Locations as Affected by Nitrogen Applied to Corn the Preceding Year (4-Year Average)

N applied to corn, lb/acre	Soybean yield Aledo	Dixon	Elwood	Kewanee	Average
	bushels per acre				
0	48	40	37	40	41
80	49	40	36	38	41
160	48	39	36	40	41
240	48	42	36	40	41
320	48	42	36	37	41

Table 11.10. Yield of Continuous Soybeans with Rates of Added Nitrogen at Hartsburg

Nitrogen, lb/acre/year	Soybean yield 1968-71	1954-71
	bushels per acre	
0	43	37
40	42	36
120	43	37

Table 11.11. Soybean Yields at Urbana as Affected by High Rates of Nitrogen

Nitrogen, lb/acre			Soybean yield, bu/acre		
1st year	2nd year	3rd year	1st year	2nd year	3rd year
0	0	0	54	53	40
40	200	200	54	57	41
80	400	400	56	57	45
120	800	800	53	55	42
160	1,600	1,600	55	34	36

would not pay for the added nitrogen at current prices.

Wheat, oats, and barley. The rate of nitrogen to apply on wheat, oats, and barley is dependent on soil type, crop and variety to be grown, and future cropping intentions (Table 11.12). Light-colored soils (low in organic matter) require the highest rate of nitrogen application because they have a low capacity to supply nitrogen. Deep, dark-colored soils require lower rates of nitrogen application for maximum yields. Estimates of organic-matter content for soils of Illinois may be obtained from Agronomy Fact Sheet SP-36, *Average Organic Matter Content in Illinois Soil Types*, or by using University of Illinois publication AG-1941, *Color Chart for Estimating Organic Matter in Mineral Soils.*

Nearly all modern varieties of wheat have been selected for improved standability; thus concern about nitrogen-induced lodging has decreased considerably. Varieties of oats, though substantially improved with regard to standability, will still lodge occasionally; and nitrogen should be used carefully. Barley varieties, especially varieties of spring barley, are prone to lodging; thus rates of nitrogen application shown in Table 11.12 should not be exceeded.

Some wheat and oats in Illinois serve as a companion crop for legume or legume-grass seedings. On those fields, it is best to apply nitrogen fertilizer at well below the optimum rate because unusually heavy vegetative growth of wheat or oats competes unfavorably with the young forage seedlings (Table 11.12). Seeding rates for small grains should also be somewhat lower if used as companion seedings.

The introduction of nitrification inhibitors and improved application equipment now provide two options for applying nitrogen to wheat. Research has shown that when the entire amount of nitrogen needed is applied in the fall with a nitrification inhibitor, the resulting yields are equivalent to that obtained when a small portion of the total need was fall-applied and the remainder was applied in early spring. Producers who are frequently delayed in applying nitrogen in the spring because of muddy fields may wish to consider fall application with a nitrification inhibitor. For fields that are not usually wet in the spring, either system of application will provide equivalent yields.

The amount of nitrogen needed for good fall growth is not large because the total uptake in roots and tops before cold weather is not likely to exceed 30 to 40 pounds per acre.

Hay and pasture grasses. The species grown, period of use, and yield goal determine optimum nitrogen fertilization (Table 11.13). The lower rate of application is recommended on fields where inadequate stands or moisture limits production.

Kentucky bluegrass is shallow-rooted and susceptible to drought. Consequently, the most efficient use of nitrogen by bluegrass is from an early spring application, with September application a second choice. September fertilization stimulates both fall and early spring growth.

Orchardgrass, smooth bromegrass, tall fescue, and reed canarygrass are more drought-tolerant than bluegrass and can use higher rates of nitrogen more effectively. Because more uniform pasture production is obtained by splitting high rates of nitrogen, two or more applications are suggested.

If extra spring growth can be utilized, make the first nitrogen application in March in southern Illinois, early April in central Illinois, and mid-April in northern Illinois. If spring growth is adequate without extra nitrogen, the first application may be delayed until after the first harvest or grazing cycle to distribute production more uniformly throughout the summer. Total production likely will be less, however, if nitrogen is applied after first harvest rather than in early spring. Usually the second application of nitrogen is made after the first harvest or first grazing cycle; to stimulate fall growth, however, this application may be deferred until August or early September.

Legume-grass mixtures should not receive nitrogen if legumes make up at least 30 percent of the mixture.

Table 11.12. Recommended Nitrogen Application Rates for Wheat, Oats, and Barley

Soil situation	Organic-matter content	Fields with alfalfa or clover seeding		Fields with no alfalfa or clover seeding	
		Wheat	Oats and barley	Wheat	Oats and barley
		nitrogen, pounds per acre			
Soils low in capacity to supply nitrogen: inherently low in organic matter (forested soils)	<2%	70-90	60-80	90-110	70-90
Soils medium in capacity to supply nitrogen: moderately dark-colored soils	2-3%	50-70	40-60	70-90	50-70
Soils high in capacity to supply nitrogen: all deep, dark-colored soils	>3%	30-50	20-40	50-70	30-50

Table 11.13. Nitrogen Fertilization of Hay and Pasture Grasses

Species	Early spring	After first harvest	After second harvest	Early September
	-------- nitrogen, pounds per acre --------			
Kentucky bluegrass......	60-80			(see text)
Orchardgrass	75-125	75-125		
Smooth bromegrass	75-125	75-125		50[a]
Reed canarygrass........	75-125	75-125		50[a]
Tall fescue for winter use		100-125	100-125	50[a]

[a] Optional if extra fall growth is needed.

Table 11.14. Adjustments in Nitrogen Recommendations

Crop to be grown	After soybeans	1st year after alfalfa or clover, Plants/sq ft: 5	2-4	<2	2nd year after alfalfa or clover, Plants/sq ft: 5	<5	Manure
	Factors resulting in reduced nitrogen requirement						
	------------ nitrogen reduction, lb/acre ------------						
Corn.........	40	100	50	0	30	0	5[a]
Wheat	10	30	10	0	0	0	5[a]

[a] Nitrogen contribution in pounds per ton of manure.

Because the main objective is to maintain the legume, the emphasis should be on applying phosphorus and potassium rather than nitrogen.

After the legume has declined to less than 30 percent of the mixture, the objective of fertilizing is to increase the yield of grass. The suggested rate of nitrogen is about 50 pounds per acre when legumes make up 20 to 30 percent of the mixture.

Rate adjustments

In addition to determining nitrogen rates, consideration should be given to other agronomic factors that influence available nitrogen. These factors include past cropping history and the use of manure (Table 11.14), as well as the date of planting.

Previous crop. Corn following another crop consistently yields better than continuous corn. This is especially true for corn following a legume such as soybeans or alfalfa (Figure 11.06). This is due in part to residual nitrogen from the legumes as the differences in yield between rotations become smaller with increasing nitrogen rates. When no nitrogen was applied, the data indicate that soybeans and alfalfa contributed the equivalent of 65 and 108 pounds of nitrogen per acre, respectively. At the optimum production level, soybeans contributed the equivalent of about 30 pounds of nitrogen per acre. The contribution of legumes, either soybeans or alfalfa, to wheat will be less than the contribution to corn because the oxidation of the organic nitrogen from these legumes will not be as rapid in early spring, when nitrogen needs of small grain are greatest, as it is in the summer, when nitrogen needs of corn are greatest.

Corn following oats had a higher yield than continuous corn (Figure 11.06). Although oats are not a legume, a part of this yield differential may be due to nitrogen released from the soil after the oat crop had completed its nitrogen uptake, and thus it was carried over to the next year's corn crop.

Idled acres. Depending on the crop grown, the nitrogen credit from idled acres may be positive or negative. Plowing under a good stand of a legume that had good growth will result in a contribution of 60 to 80 pounds of nitrogen per acre. If either stand or growth of the legume was poor or if corn was zero-

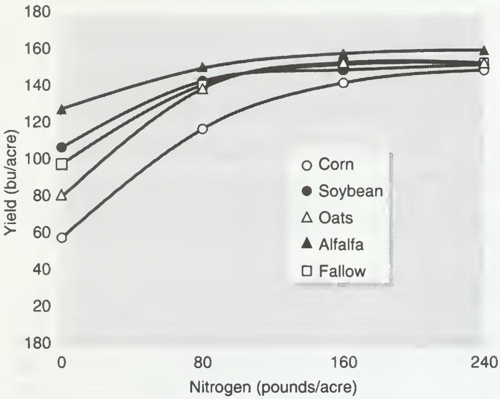


Figure 11.06. Effect of crop rotation and applied nitrogen on corn yield, DeKalb.

tilled into a good legume stand that had good growth, the legume nitrogen contribution could be reduced to 40 to 60 pounds per acre. Because most of the net nitrogen gained from first-year legumes will be in the herbage, fall grazing will reduce the nitrogen contribution to 30 to 50 pounds per acre. If sorghum residues are incorporated into the soil, an additional 30 to 40 pounds of nitrogen should be applied per acre.

Manure. Nutrient content of manure will vary, depending on source and method of handling (Table 11.15). Additionally, the availability of the total nitrogen content will vary, depending on method of application. When incorporated during or immediately after application, about 50 percent of the total nitrogen in dry manure and 50 to 60 percent of the total nitrogen in liquid manure will be available for the crop that is grown during the year following manure application.

Time of planting. Research at the Northern Illinois Research Center for several years showed that as planting was delayed, less nitrogen fertilizer was required for most profitable yield. Based upon that research, Illinois agronomists suggest that for each week of delay in planting after the optimum date for

Table 11.15. Average Composition of Manure

Kind of animal	Nutrients (lb/ton) Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)
Dairy cattle	11	5	11
Beef cattle	14	9	11
Hogs	10	7	8
Chicken	20	16	8
Dairy cattle (liquid)	5(26)[a]	2(11)	4(23)
Beef cattle (liquid)	4(21)	1(7)	3(18)
Hogs (liquid)	10(56)	5(30)	4(22)
Chicken (liquid)	13(74)	12(68)	5(27)

[a] Parenthetical numbers are pounds of nutrients per 1,000 gallons.

the area, the nitrogen rate can be reduced 20 pounds per acre down to 80 to 90 pounds per acre as the minimum for very late planting in a corn-soybean cropping system. Suggested reference dates are April 10 to 15 in southern Illinois, April 20 to May 1 in central Illinois, and May 1 to 10 in northern Illinois. This adjustment is, of course, possible only if the nitrogen is sidedressed.

Because of the importance of the planting date, farmers are encouraged not to delay planting just to apply nitrogen fertilizer: plant, then sidedress.

Reactions in the soil

Efficient use of nitrogen fertilizer requires an understanding of how nitrogen behaves in the soil. Key points to consider are the change from ammonium (NH_4^+) to nitrate (NO_3^-) and the movements and transformations of nitrate.

A high percentage of the nitrogen applied in Illinois is in the ammonium form or converts to ammonium (anhydrous ammonia and urea, for example) soon after application. Ammonium nitrogen is held by the soil clay and organic matter and cannot move very far until it nitrifies (changes from ammonium to nitrate). In the nitrate form, nitrogen can be lost by either denitrification or leaching (Figure 11.07).

Denitrification. Denitrification is believed to be the main process by which nitrate and nitrite nitrogen are lost, except on sandy soils, where leaching is the major pathway. Denitrification involves only nitrogen that is in the form of either nitrate (NO_3^-) or nitrite (NO_2^-).

The amount of denitrification depends mainly on (a) how long the surface soil is saturated; (b) the temperature of the soil and water; (c) the pH of the soil; and (d) the amount of energy material available to denitrifying organisms.

When water stands on the soil or when the surface is completely saturated in late fall or early spring, nitrogen loss is likely to be small because (a) much nitrogen is still in the ammonium rather than nitrate form; and (b) the soil is cool, and denitrifying organisms are not very active.

Many fields in east-central Illinois and, to a lesser extent, in other areas have low spots where surface water collects at some time during the spring or early summer. The flat claypan soils also are likely to be

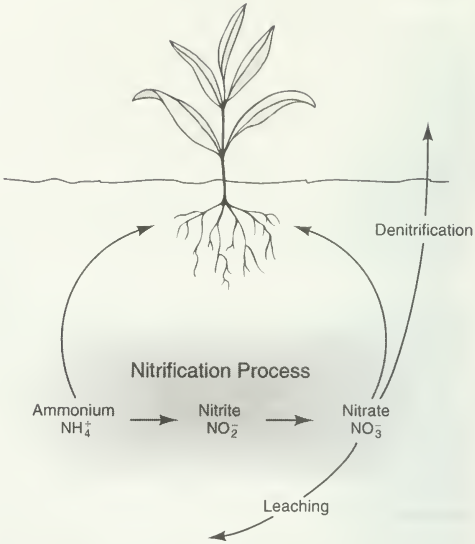


Figure 11.07 Nitrogen reactions in the soil.

saturated, though not flooded, during that time. Sidedressing would avoid the risk of spring loss on these soils but would not affect midseason loss. Unfortunately, these are the soils on which sidedressing is difficult in wet years.

New scientific procedures now make it possible to directly measure denitrification losses. Results collected over the past few years indicate that when soils were saturated for 3 to 4 days, losses of 25 to 40 percent of the nitrogen present as nitrate occurred even though water was ponded for only a few hours. These losses resulted in a yield loss of 10 to 20 bushels per acre. Increasing the time that soils were saturated to 6 days resulted in losses of 50 to 60 percent of the nitrogen present as nitrate. As more results are collected, agronomists will be able to predict more accurately the nitrogen loss under specific conditions and, more importantly, to predict the response to added nitrogen.

Leaching. In silt loams and clay loams, 1 inch of rainfall moves down about 5 to 6 inches, though some of the water moves in large pores farther through the profile and carries nitrates with it.

In sandy soils, each inch of rainfall moves nitrates down about 1 foot. If the total rainfall at one time is more than 6 inches, little nitrate will be left within the rooting depth on sands.

Between rains, some upward movement of nitrates occurs in moisture that moves toward the surface as the surface soil dries. The result is that it is difficult to predict how deep the nitrate has moved based only on cumulative rainfall.

When trying to estimate the depth of leaching of nitrates in periods of very intensive rainfall, two points need to be considered. First, the rate at which water can enter the surface of silt and clay loams may be less than the rate of rainfall, which means that much of the water runs off the surface either into low spots or into creeks and ditches. Second, the soil may be saturated already. In either of these cases, the nitrates will not move down the 5 to 6 inches per inch of rain as suggested above.

Corn roots usually penetrate to 6 feet in Illinois soils. Thus, nitrates that leach only to 3 to 4 feet are well within normal rooting depth unless they reach tile lines and are drained from the field.

Nitrification inhibitors

As Figure 11.07 shows, nitrification converts ammonium nitrogen into the nitrate form of nitrogen and thereby increases the potential for loss of soil nitrogen. Use of nitrification inhibitors can retard this conversion. When inhibitors were properly applied in one experiment, as much as 42 percent of soil-applied ammonia remained in the ammonium form through the early part of the growing season, in contrast with only 4 percent that remained when inhibitors were not used. Inhibitors can therefore have a significant effect on crop yields. The benefit from using an inhibitor will vary, however, with the soil condition, time of year, type of soil, geographic location, rate of nitrogen application, and weather conditions that occur after the nitrogen is applied and before it is absorbed by the crop.

Considerable research throughout the Midwest has shown that only under wet soil conditions will inhibitors significantly increase yields. When inhibitors were applied in years of excessive rainfall, increases in corn yield ranged from 10 to 30 bushels per acre; when moisture conditions were not as conducive to denitrification or leaching, inhibitors produced no increase.

For the first 4 years of one experiment conducted by the University of Illinois, nitrification inhibitors produced no effect on grain yields because soil moisture levels were not sufficiently high. In early May of the fifth year, however, when soils were saturated with water for a long time, the application of an inhibitor in the preceding fall significantly increased corn yields (Figure 11.08). Furthermore, at a nitrogen application rate of 150 pounds per acre, the addition of an inhibitor increased grain yields more than did the addition of another 40 pounds of nitrogen (Figure 11.08). Under the conditions of that experiment, therefore, it was more economical to use an inhibitor than to apply more nitrogen.

Because soils normally do not remain saturated with water for very long during the growing season after a sidedressing operation, the probability of benefiting from the use of a nitrification inhibitor with sidedressed nitrogen is less than from their use with either fall- or spring-applied nitrogen. Moreover, the short time

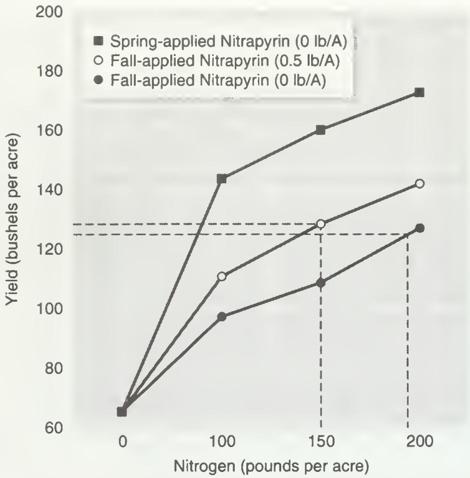


Figure 11.08. Effect of nitrification inhibitors on corn yields at varying nitrogen application rates, DeKalb.

between application and absorption by the crop greatly reduces the potential for nitrogen loss.

The longer the period between nitrogen application and absorption by the crop, the greater the probability that nitrification inhibitors will contribute to higher yields. The length of time, however, that fall-applied inhibitors will remain effective in the soil is partly dependent on soil temperature. On one plot, a Drummer soil that had received an inhibitor application when soil temperatures were 55°F retained nearly 50 percent of the applied ammonia in ammonium form for about 5 months. When soil temperatures were 70°F, it retained the same amount of ammonia for only 2 months. Fall application of nitrogen with inhibitors should therefore be delayed until soil temperatures are no higher than 60°F; and though temperatures may decrease to 60°F in early September, it is advisable to delay applications until the second week in October in northern Illinois and the third week in October in central Illinois.

In general, poorly or imperfectly drained soils will probably benefit the most from nitrification inhibitors. Moderately well-drained soils that undergo frequent periods of 3 or more days of flooding in the spring will also benefit. Coarse-textured soils (sands) are likely to benefit more than soils with finer textures because the coarse-textured soils have a higher potential for leaching.

Time of application and geographic location must be considered along with soil type when determining whether to use a nitrification inhibitor. Employing nitrification inhibitors can significantly improve the efficiency of fall-applied nitrogen on the loams, silts, and clays of central and northern Illinois in years when the soil is very wet in the spring. At the same time,

currently available inhibitors will not adequately reduce the rate of nitrification in the low organic-matter soils of southern Illinois when nitrogen is applied in the fall for the following year's corn. The lower organic-matter content and the warmer temperatures of southern Illinois soils, both in late fall and early spring, will cause the inhibitor to degrade too rapidly. Futhermore, applying an inhibitor on sandy soils in the fall will not adequately reduce nitrogen loss because the potential for leaching is too high. Therefore, fall applications of nitrogen with inhibitors are not recommended for sandy soils or for soil with low organic-matter content, especially for those soils found south of Interstate Highway 70.

In the spring, preplant applications of inhibitors may be beneficial on nearly all types of soil from which nitrogen loss frequently occurs, especially on sandy and poorly drained soils. Again, inhibitors are more likely to have an effect when subsoils are recharged with water than when subsoils are dry at the beginning of spring.

Nitrification inhibitors are most likely to increase yields when nitrogen is applied at or below the optimum rate. When nitrogen is applied at a rate greater than that required for optimum yields, benefits from an inhibitor are unlikely, even when moisture in the soil is excessive.

Inhibitors should be viewed as soil management tools that can be used to reduce nitrogen loss. It is not safe to assume, however, that the use of a nitrification inhibitor will make it possible to reduce nitrogen rates below those currently recommended, because those rates were developed with the assumption that no significant amount of nitrogen would be lost.

Time of nitrogen application

When nitrogen is fall-applied without a nitrification inhibitor, farmers in central and northern Illinois are encouraged to apply nitrogen in non-nitrate form in the late fall any time after the soil temperature at 4 inches was below 50°F, except on sandy, organic, or very poorly drained soils.

The 50°F level for fall application is believed to be a realistic guideline for farmers. Applying nitrogen earlier involves risking too much loss (Figure 11.09). Later application involves risking wet or frozen fields, which would prevent application and fall tillage. Average dates on which these temperatures are reached are not satisfactory guides because of the great variability from year to year. Soil thermometers should be used to guide fall applications of nitrogen.

In Illinois, most of the nitrogen applied in late fall or very early spring will be converted to nitrate by corn-planting time. Though the rate of nitrification is slow (Figure 11.09), the soil temperature is between 32°F and 40° to 45°F for a long period.

In consideration of the date at which nitrates are formed and the conditions that prevail thereafter, the difference in susceptibility to denitrification and leach-

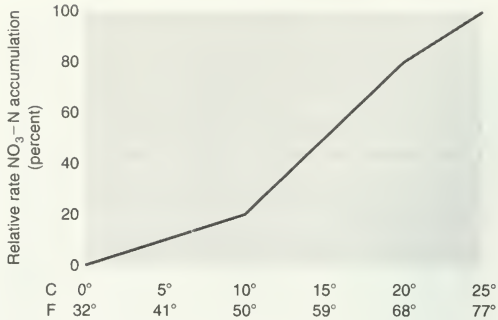


Figure 11.09. Influence of soil temperature on the relative rate of NO_3 accumulation in soils.

ing loss between late fall and early spring applications of ammonium sources is probably small. Both are, however, more susceptible to loss than is nitrogen applied at planting time or as a sidedressing.

Anhydrous ammonia nitrifies more slowly than other forms and is slightly preferred for fall applications. It is well suited to early spring application, provided the soil is dry enough for good dispersion of ammonia and closure of the applicator slit.

Sidedress application. Results collected from studies in Illinois indicated that nitrogen injected between every other row was comparable in yield to injection between every row. This finding was true irrespective of tillage system (Table 11.16) or nitrogen rate (Table 11.17). This outcome should be expected, as even with every-other-row injection, each row will have nitrogen applied on one side or the other (Figure 11.10).

Table 11.16. Effect on Corn Yield of Ammonia Knife Spacing with Different Tillage Systems at Two Locations in Illinois

	Yield, bushels per acre			
Injector spacing, inches	Plow	Chisel	Disk	No-Till
	DeKalb			
30	159	157	163	146
60	158	157	157	143
	Elwood			
30	...	119	121	118
60	...	117	125	121

Table 11.17. Effect on Corn Yield of Injector Spacing of Ammonia Applied at Different Rates of Nitrogen, DeKalb

	Nitrogen, lb/acre		
Injector spacing, inches	120	180	240
	yield, bu/acre		
30	171	176	181
60	170	171	182

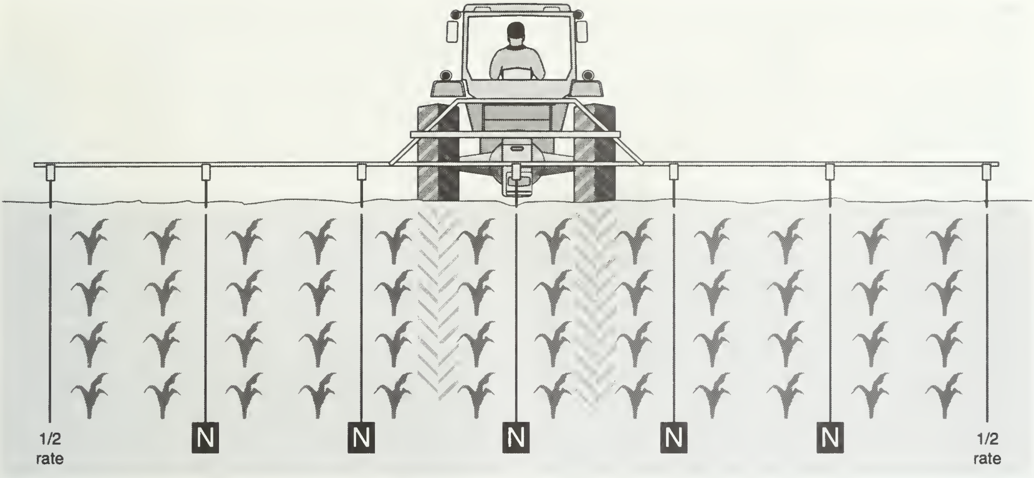


Figure 11.10. Schematic of every-other-row, sidedress nitrogen injection.
NOTE: The outside two injectors are set at one-half rate because the injector will run between those two rows twice.

Use of wider injection spacing at sidedressing allows for a reduction in power requirement for a given applicator width or use of a wider applicator with the same power requirement. From a practical standpoint, the lower power requirement will frequently mean a smaller tractor and associated smaller tire, making it easier to maneuver between the rows and also giving less compaction next to the row. With this system, injector positions can be adjusted to avoid placing an injector in the wheel track. When matching the driving pattern for planters of 8, 12, 16, or 24 rows, the outside two injectors must be adjusted to half-rate application, as the injector will go between those two rows twice if one avoids having a knife in the wheel track. To avoid problems of back pressure that might be created when applying at relatively high rates of speed, use a double-tube knife, with two hoses going to each knife; the outside knives would require only one hose to give the half-rate application.

Winter application. Based on observations, the risk of nitrogen loss through volatilization associated with winter application of urea for corn on frozen soils is too great to consider the practice unless one is assured of at least ½ inch of precipitation occurring within 4 to 5 days after application. In most years, application of urea on frozen soils has been an effective practice for wheat.

Aerial application. Recent research at the University of Illinois has indicated that an aerial application of dry urea will result in increased yield. This practice should not be considered a replacement for normal nitrogen application but rather an emergency treatment in situations where corn is too tall for normal applicator equipment. Aerial application of nitrogen solutions on growing corn is not recommended, as extensive leaf damage will likely result if the rate of application is greater than 10 pounds of nitrogen per acre.

Which nitrogen fertilizer?

Most of the nitrogen fertilizer materials available for use in Illinois provide nitrogen in the combined form of ammonia, ammonium, urea, and nitrate (Table 11.18). For many uses on a wide variety of soils, all forms are likely to produce about the same yield — provided that they are properly applied.

Ammonia. Nitrogen materials that contain free ammonia (NH_3), such as anhydrous ammonia or low-pressure solutions, must be injected into the soil to avoid loss of ammonia in gaseous form. Upon injection into the soil, ammonia quickly reacts with water to form ammonium (NH_4^+). In this positively charged form, the ion is not susceptible to gaseous loss because it is temporarily attached to the negative charges on clay and organic matter. Some of the ammonia reacts with organic matter to become a part of the soil humus.

On silt loam or soils with finer textures, ammonia will move about 4 inches from the point of injection. On more coarsely textured soils such as sands, ammonia may move 5 to 6 inches from the point of injection. If the depth of application is shallower than the distance of movement, some ammonia may move slowly to the soil surface and escape as a gas over a period of several days. On coarse-textured (sandy) soils, anhydrous ammonia should be placed 8 to 10 inches deep, whereas on silt-loam soils, the depth of application should be 6 to 8 inches. Anhydrous ammonia is lost more easily from shallow placement than

Table 11.18. Composition of Various Nitrogen Fertilizers

Material	Total nitrogen %	Percent of total nitrogen as				Salting out temperature	Weight of solution per gallon
		Ammonia	Ammonium	Nitrate	Urea		
Anhydrous ammonia...	82	100	—	—	—	—	5.90
Ammonium nitrate	34	—	50	50	—	—	—
Ammonium sulfate	21	—	100	—	—	—	—
Urea	46	—	—	—	100	—	—
Urea-ammonium nitrate	28	—	25	25	50	-1	10.70
Urea-ammonium nitrate	32	—	25	25	50	32	11.05

is ammonia in low-pressure solutions. Nevertheless, low-pressure solutions contain free ammonia and thus need to be incorporated into the soil at a depth of 2 to 4 inches. Ammonia should not be applied to soils having a physical condition that would prevent closure of the applicator knife track. Ammonia will escape to the atmosphere whenever there is a direct opening from the point of injection to the soil surface.

Seedlings can be damaged if proper precautions are not taken when applying nitrogen materials that contain or form free ammonia. Damage may occur if nitrogen material is injected into soils that are so wet that the knife track does not close properly. If the soil dries rapidly, this track may open. Damage can also result from applying nitrogen material to excessively dry soils, which allow the ammonia to move large distances before being absorbed. Finally, damage to seedlings can be caused by using a shallower application than that suggested in the preceding paragraph. Generally, delaying planting 3 to 5 days after applying fertilizer will cause little, if any, seedling damage. While it is extremely rare, damage from fall-applied ammonia to corn seeded the next spring has been observed. The situations where this has occurred have been characterized by application in late fall on soils that were wet enough that serious compaction resulted along the side walls of the knife track. This was followed by an extremely dry winter and spring. When the surface soils dried in the spring, the soil cracked along the knife track and allowed the ammonia to escape into the seed zone.

Ammonium nitrate. Half of the nitrogen contained in ammonium nitrate is in the ammonium form, and half is in the nitrate form. The part present as ammonium attaches to the negative charges on the clay and organic-matter particles and remains in that state until it is used by the plant or converted to the nitrate ions by microorganisms present in the soil. Because 50 percent of the nitrogen is present in the nitrate form, this product is more susceptible to loss from both leaching and denitrification. Thus, ammonium nitrate should not be applied to sandy soils because of the likelihood of leaching, nor should it be applied far in advance of the time when the crop needs the nitrogen because of possible loss through denitrification.

Urea. The chemical formula for urea is $CO(NH_2)_2$. In this form, it is very soluble and moves freely up and down with soil moisture. After being applied to the soil, urea is converted to ammonia, either chemically or by the enzyme urease. The speed with which this conversion occurs depends largely on temperature. At low temperatures, conversion is slow; but at temperatures of 55°F or higher, conversion is rapid.

If the conversion of urea occurs on the soil surface or on the surface of crop residue or leaves, some of the resulting ammonia will be lost as a gas to the atmosphere. The potential for loss is greatest when:

- Temperatures are greater than 55°F. Loss is less likely with winter or early spring applications, but results show that the loss may be substantial if the materials remain on the surface of the soil for several days.
- Considerable crop residue remains on soil surface.
- Application rates are greater than 100 pounds of nitrogen per acre.
- The soil surface is moist and rapidly drying.
- Soils have a low cation-exchange capacity.
- Soils are neutral or alkaline in reaction.

Research conducted at both the Brownstown and Dixon Springs research centers has shown that surface application of urea for no-till corn did not yield as well as ammonium nitrate in most years (Table 11.19). In years when a rain was received within 1 or 2 days after application, urea resulted in as good a yield increase as did ammonium nitrate (that is, compared to results from early spring application of ammonium nitrate at Dixon Springs in 1975). In other studies, urea that was incorporated soon after application yielded as well as ammonium nitrate.

Urease inhibitor. Chemical compound N-(n-butyl) thiophosphoric triamide, commonly referred to as NBPT, has been shown to inhibit the urease enzyme that converts urea to ammonia. This material, scheduled for release to the market for the 1995 crop year, will be sold as a product that could be added to urea-ammonium nitrate solutions or to urea in the manufacturing process. Addition of this material will reduce the potential for volatilization of surface-applied, urea-containing products. Experimental results collected around the Corn Belt over the last several years have shown an average increase of 4.3 bushels per acre when applied with urea and 1.6 bushels per acre when applied with urea-ammonium nitrate solutions. Where nonvolatile nitrogen treatments resulted in a higher yield than unamended urea, addition of the urease

Table 11.19. Effect of Source of Nitrogen on Yield for No-Till Corn

Source	Nitrogen: Date of application	Nitrogen: Method of application	Nitrogen: Rate, lb/acre	Brownstown 1974-77 avg.	Dixon Springs 1974	Dixon Springs 1975
				yield, bu/acre		
Control....	...	...	0	52	50	...
Ammonium nitrate...	early spring	surface	120	96	132	160
Urea	early spring	surface	120	80	106	166
Ammonium nitrate...	early June	surface	120	106	151	187
Urea	early June	surface	120	99	125	132

inhibitor increased yield by 6.6 bushels per acre for urea and by 2.7 bushels per acre for urea-ammonium nitrate solutions. In a year characterized by a long dry period in the spring, NBPT with urea resulted in yield increases of 20 bushels per acre as compared to urea alone in related experiments in Southern Illinois and Missouri (Table 11.20 and Table 11.21). These results clearly show the importance of using proper urea management techniques in years when precipitation is not received soon after surface application of urea.

Urease inhibitors have the greatest potential for benefit when urea-containing materials are surface-applied without incorporation at 50°F or higher. The potential is even greater if there is significant residue remaining on the soil surface. In situations where the urea-containing materials can be incorporated within 2 days after application, either with a tillage operation or with adequate rainfall, the potential for benefit from a urease inhibitor is very low.

Ammonium sulfate. The compound ammonium sulfate ($[NH_4]_2SO_4$) supplies all of the nitrogen in the ammonium form. As a result, it theoretically has a slight advantage over products that supply a portion of their nitrogen in the nitrate form, because the ammonium form is not susceptible to leaching or denitrification. However, this advantage is usually short-lived because all ammonium-based materials quickly convert to nitrate once soil temperatures are favorable for activity of soil organisms (soil temperatures above 50°F).

Table 11.20. Effect of N Source, Rate, and NBPT on No-Till Corn Yield in Southern Illinois

N lb/acre	N Source: Ammonium Nitrate	N Source: Urea	N Source: Urea + NBPT
	Yield bu/acre		
0	60		
80	114	90	110
120	118	97	115
160	114	105	122

Source: Southern Illinois University, Dr. E. C. Varsa. 1992.

In contrast to urea, there is little risk of loss of the ammonium contained in ammonium sulfate through volatilization. As a result, it is an excellent material for surface application on fields that will be planted no-till that have high-residue levels. As with any ammonium-based material, there is a risk associated with surface application in years in which there is inadequate precipitation to allow for adequate root activity in the fertilizer zone.

Ammonium sulfate is an excellent material to use on soils that may be deficient in both nitrogen and sulfur. However, application of the material at a rate sufficient to meet the nitrogen need will cause over-application of sulfur. That is not of concern because sulfur is mobile and will move out of the profile quickly. Fortunately, there is no known environmental problem associated with sulfur in water supplies.

Most of the ammonium sulfate available in the marketplace is a by-product of the steel, textile, or lysine industry and is marketed as either a dry granulated material or as a slurry.

Ammonium sulfate is more acidifying than any of the other nitrogen materials on the market. As a rough rule, ammonium sulfate requires about 9 pounds of lime per pound of nitrogen applied, compared to 4 pounds of lime per pound of nitrogen from ammonia or urea. The extra acidity is of no concern as long as the soil is monitored for pH every 4 years.

In areas where fall application is acceptable, ammonium sulfate could be applied in late fall (after temperatures have fallen below 50°F) or in winter on frozen ground where the slope is less than 5 percent.

Nitrogen solutions. The nonpressure nitrogen solutions that contain 28 to 32 percent nitrogen consist of a mixture of urea and ammonium nitrate. Typically, half of the nitrogen is from urea, and the other half is from ammonium nitrate. The constituents of these compounds will undergo the same reactions as described above for the constituents applied alone.

Experiments at DeKalb have shown a yield difference between incorporated and unincorporated nitrogen solutions that were spring-applied (Table 11.22). This difference associated with method of application is probably caused by volatilization loss of some nitrogen from the surface-applied solution containing urea.

The effect on yield of postemergence application of nitrogen solutions and atrazine when corn plants are

Table 11.21. Effect of N Source, Rate, and NBPT on No-Till Corn Yield in Missouri

N lb/acre	N Source: Ammonium Nitrate	N Source: Urea	N Source: Urea + NBPT
	Yield bu/acre		
0	83	—	—
60	164	132	151
180	203	173	196

Source: University of Missouri, Dr. Daryl Buchholz.

Table 11.22. Effect of Source, Method of Application, and Rate of Spring-Applied Nitrogen on Corn Yield, DeKalb

Carrier and method of application	N, lb/acre	Year 1976	1977	Avg.
		yield, bu/acre		
None	0	66	61	64
Ammonia	80	103	138	120
28 percent N solution, incorporated	80	98	132	115
28 percent N solution, unincorporated	80	86	126	106
Ammonia	160	111	164	138
28 percent N solution, incorporated	160	107	157	132
28 percent N solution, unincorporated	160	96	155	126
Ammonia	240	112	164	138
28 percent N solution, incorporated	240	101	164	132
28 percent N solution, unincorporated	240	91	153	122
LSD$_{.10}$[a]		9.1	5.2	

[a] Differences greater than the LSD value are statistically significant.

in the three-leaf stage was evaluated in Minnesota. The results there indicated that yields were generally depressed when the nitrogen rate exceeded 60 pounds per acre. Leaf burn was increased by increasing the nitrogen rate, including atrazine with the nitrogen, and by hot, clear weather conditions.

Phosphorus and potassium

Inherent availability

Illinois has been divided into three regions in terms of the inherent phosphorus-supplying power of the soil below the plow layer in dominant soil types (see Figure 11.11).

High phosphorus-supplying power means that the soil test for available phosphorus (P_1 test) is relatively high and conditions are favorable for good root penetration and branching throughout the soil profile.

Low phosphorus-supplying power may be caused by one or more of these factors:

1. A low supply of available phosphorus in the soil profile because (a) the parent material was low in phosphorus; (b) phosphorus was lost in the soil-forming process; or (c) the phosphorus is made unavailable by high pH (calcareous) material.
2. Poor internal drainage that restricts root growth.
3. A dense, compact layer that inhibits root penetration or branching.
4. Shallowness to bedrock, sand, or gravel.
5. Droughtiness, strong acidity, or other conditions that restrict crop growth and reduce rooting depth.

Regional differences in phosphorus-supplying power are shown in Figure 11.11. Parent material and degree

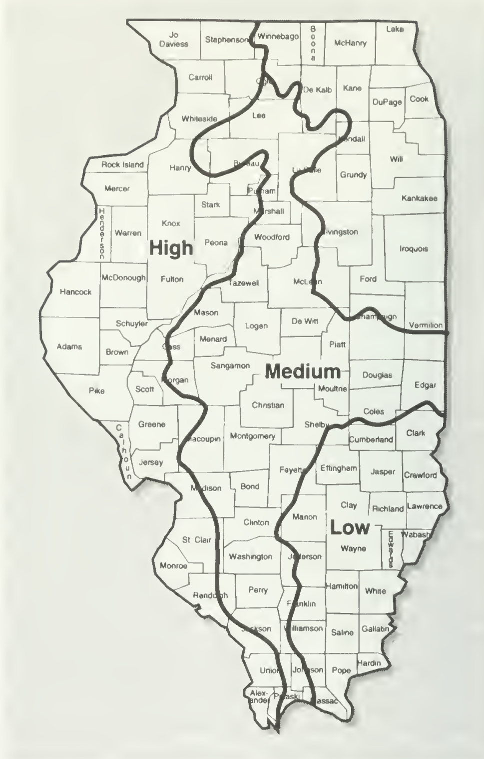


Figure 11.11. Phosphorus-supplying power.

of weathering were the primary factors considered in determining the various regions.

The "high" region is in western Illinois, where the primary parent material was more than 4 to 5 feet of loess that was high in phosphorus content. The soils are leached of carbonates to a depth of more than 3½ feet, and roots can spread easily in the moderately permeable profiles.

The "medium" region is in central Illinois, with arms extending into northern and southern Illinois. The primary parent material was more than 3 feet of loess over glacial till, glacial drift, or outwash. Some sandy areas with low phosphorus-supplying power occur in the region. In comparison with the high-phosphorus region, more of the soils are poorly drained and have less available phosphorus in the subsoil and substratum horizons. Carbonates are likely to occur at shallower depths than in the "high" region. The soils in the northern and central areas are generally free of root restrictions, whereas soils in the southern arm are more likely to have root-restricting layers within the profile. The phosphorus-supplying power of soils of

the region is likely to vary with natural drainage. Soils with good internal drainage are likely to have higher levels of available phosphorus in the subsoil and substratum. If internal drainage is fair or poor, phosphorus levels in the subsoil and substratum are likely to be low or medium.

In the "low" region in southeastern Illinois, the soils were formed from 2½ to 7 feet of loess over weathered Illinoisan till. The profiles are more highly weathered than in the other regions and are slowly or very slowly permeable. Root development is more restricted than in the "high" or "medium" regions. Subsoil levels of phosphorus may be rather high by soil test in some soils of the region, but this is partially offset by conditions that restrict rooting.

In the "low" region in northeastern Illinois, the soils were formed from thin loess (less than 3 feet) over glacial till. The glacial till, generally low in available phosphorus, ranges in texture from gravelly loam to clay in various soil associations of the region. In addition, shallow carbonates further reduce the phosphorus-supplying power of the soils of the region. Further, high bulk density and slow permeability in the subsoil and substratum restrict rooting in many soils of the region.

The three regions are delineated to show broad differences among them. Parent material, degree of weathering, native vegetation, and natural drainage vary within a region and cause variation in the soil's phosphorus-supplying power. It appears, for example, that soils developed under forest cover have more available subsoil phosphorus than those developed under grass.

Illinois is divided into two general regions for potassium, based on cation-exchange capacity (Figure 11.12). Important differences exist, however, among soils within these general regions because of differences in these factors:

1. The amount of clay and organic matter, which influences the exchange capacity of the soil.
2. The degree of weathering of the soil material, which affects the amount of potassium that has been leached out.
3. The kind of clay mineral.
4. Drainage and aeration, which influence uptake of potassium.
5. The parent material from which the soil was formed.
6. Compactness or other conditions that influence root growth.

Soils that have a cation-exchange capacity less than 12 me/100 gram are classified as having low cation-exchange capacity. These soils include the sandy soils because minerals from which these soils were developed are inherently low in potassium. Sandy soils also have very low cation-exchange capacities and thus do not hold much reserve potassium.

Silt-loam soils in the "low" area in southern Illinois (claypans) are relatively older in terms of soil development; consequently, much more of the potassium

Figure 11.12. Cation-exchange capacity.
NOTE: The shaded areas are sands with low cation-exchange capacity.

has been leached out of the rooting zone. Furthermore, wetness and a platy structure between the surface and subsoil may interfere with rooting and with potassium uptake early in the growing period, even though roots are present.

Rate of fertilizer application

Minimum soil-test levels required to produce optimum crop yields vary depending on the crop to be grown and the soil type (Figure 11.13 and Figure 11.14). Near-maximum yields of corn and soybeans will be obtained when levels of available phosphorus are maintained at 30, 40, and 45 pounds per acre for soils in the high, medium, and low phosphorus-supplying regions, respectively. Potassium soil-test levels at which optimum yields of these two crops will be attained are 260 and 300 pounds of exchangeable potassium per acre for soils in the low and high cation-exchange capacity regions, respectively. Because phosphorus, and on most soils also potassium, will not be

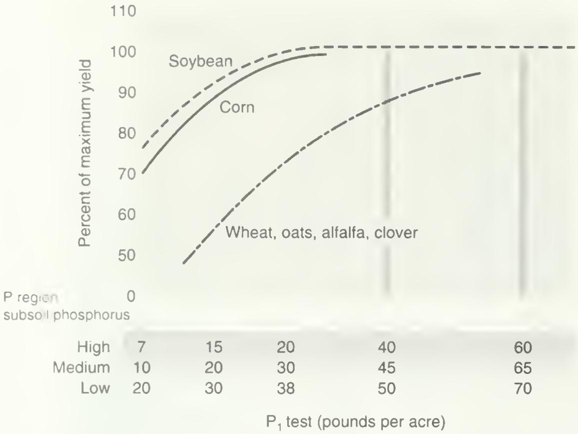


Figure 11.13. Relationship between expected yield and soil-test phosphorus.

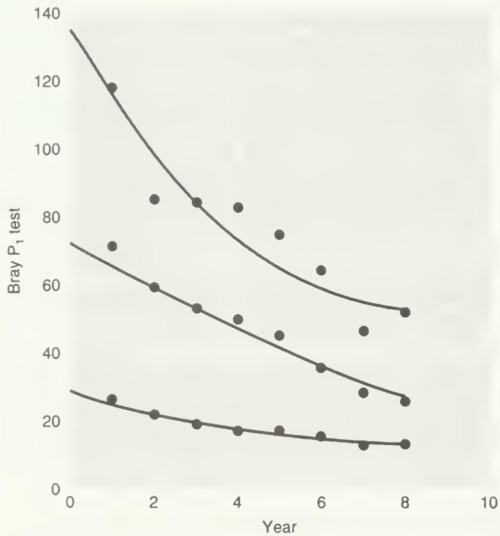


Figure 11.14. Effect of elimination of P fertilizer on P_1 soil test.

lost from the soil system other than through crop removal or soil erosion and because these are minimum values required for optimum yields, it is recommended that soil-test levels be built up to 40, 45, and 50 pounds per acre of phosphorus for soils in the high, medium, and low phosphorus-supplying regions, respectively.

Depending on the soil-test level, the amount of fertilizer recommended may consist of a buildup plus maintenance; maintenance; or no fertilizer suggestion. The buildup is the amount of material required to increase the soil test to the desired level. The maintenance addition is the amount required to replace the amount that will be removed by the crop to be grown.

Buildup plus maintenance. When soil-test levels are below the desired values, it is suggested that enough fertilizer be added to build the soil test to the desired goal plus enough to replace what the crop will remove. At these test levels, the yield of the crop to be grown will be affected by the amount of fertilizer applied that year.

Maintenance. When the soil-test levels are between the minimum and 20 pounds above the minimum for phosphorus (that is, 40 to 60, 45 to 65, or 50 to 70) or between the minimum and 100 pounds above the minimum for potassium (that is, 260 to 360 or 300 to 400), apply enough to replace what the crop to be grown is expected to remove. The yield of the current crop may not be affected by the fertilizer addition that year, but the yield of subsequent crops will be adversely affected if the materials are not applied to maintain soil-test levels.

No fertilizer. Although it is recommended that soil-test levels be maintained slightly above the level at which optimum yield would be expected, it would not be economical to attempt to maintain the values at excessively high levels. *Therefore, it is suggested that no phosphorus be applied if P_1 values are higher than 60, 65, or 70, respectively, for soils in the high, medium, and low phosphorus-supplying regions. No potassium is suggested if test levels are above 360 or 400 for the low and high cation-exchange capacity regions, unless crops that remove large amounts of potassium (such as alfalfa or corn silage) are being grown.* When soil-test levels are between 400 and 600 pounds per acre of potassium and corn silage or alfalfa is being grown, the soil should be tested every 2 years instead of 4, or maintenance levels of potassium should be added to ensure that soil-test levels do not fall below the point of optimum yields.

Consequences of omitting fertilizer. The impact of eliminating phosphorus or potassium fertilizer on yield and soil-test level will depend on the initial soil test and the number of years that applications are omitted. In a recent Iowa study, elimination of phosphorus application for 9 years decreased soil-test levels from 136 to 52 pounds per acre, but yields were not adversely affected in any year as compared to plots where soil-test levels were maintained (Figure 11.15). In the same study, elimination of phosphorus for the 9 years when the initial soil test was 29 resulted in a decrease in soil-test level to 14 and a decrease in yield to 70 percent of the yield obtained when adequate fertility was supplied. Elimination of phosphorus at an intermediate soil-test level had little impact on yield but decreased the soil-test level from 67 to 26 pounds per acre over the 9 years. These, as well as similar Illinois results, indicate that there is little if any po-

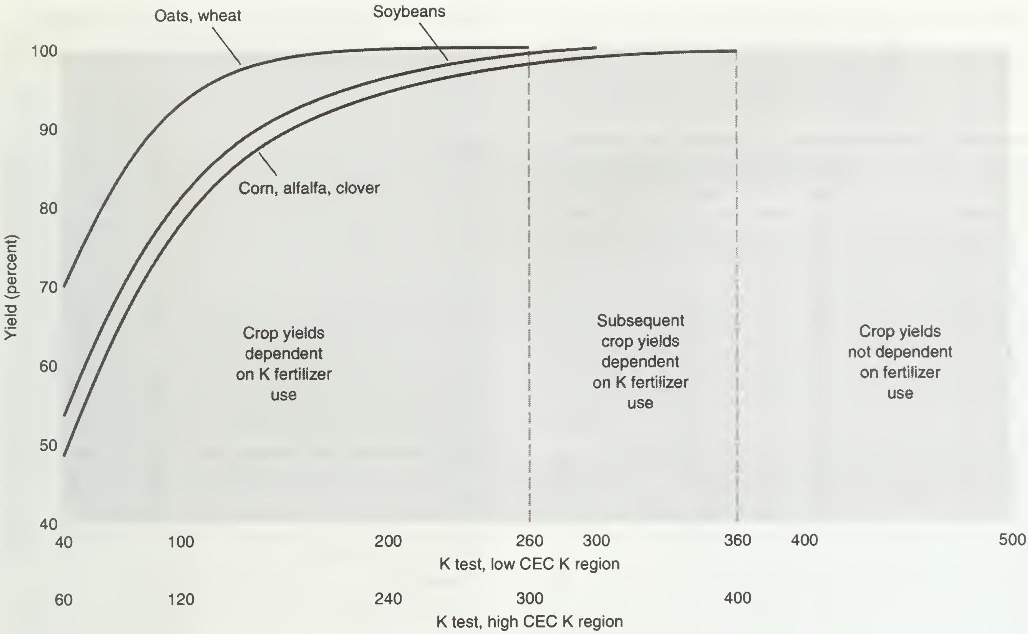


Figure 11.15. Effect of elimination of P fertilizer on P_1 soil test.

tential for a yield decrease if phosphorus application was eliminated for 4 years on soils that have a phosphorus test of 60 pounds per acre or higher.

Phosphorus

Buildup. Research has shown that, as an average for Illinois soils, 9 pounds of P_2O_5 per acre are required to increase the P_1 soil test by 1 pound. Therefore, the recommended rate of buildup phosphorus is equal to nine times the difference between the soil-test goal and the actual soil-test value. The amount of phosphorus recommended for buildup over a 4-year period for various soil-test levels is presented in Table 11.23.

Because the rate of 9 pounds of P_2O_5 to increase the soil test by 1 pound is an average for Illinois soils, some soils will fail to reach the desired goal in 4 years with P_2O_5 applied at this rate, and others will exceed the goal. Therefore, it is recommended that each field be retested every 4 years.

In addition to the supplying power of the soil, the optimum soil-test value also is influenced by the crop to be grown. For example, the phosphorus soil-test level required for optimum yields of wheat and oats (Figure 11.13) is considerably higher than that required for corn and soybean yields, partly because wheat and corn have different phosphorus uptake patterns. Wheat requires a large amount of readily available phosphorus in the fall, when the root system is feeding primarily from the upper soil surface. Phosphorus is taken up by corn until the grain is fully developed, so subsoil phosphorus is more important in interpreting the phosphorus test for corn than for wheat. To compensate for the higher phosphorus requirements of wheat and oats, it is suggested that 1.5 times the amount of expected phosphorus removal be applied prior to seeding these crops. This correction has already been included in the maintenance values listed for wheat and oats in Table 11.24.

Maintenance. In addition to adding fertilizer to build up the soil test, sufficient fertilizer should be added each year to maintain a specified soil-test level. The amount of fertilizer required to maintain the soil-test value is equal to the amount removed by the harvested portion of the crop (Table 11.24). The only exception to this guideline is that the maintenance value for wheat and oats is equal to 1.5 times the amount of phosphorus (P_2O_5) removed by the grain. This correction has already been accounted for in the maintenance values given in Table 11.24.

Potassium

As indicated, phosphorus will usually remain in the soil unless it is removed by a growing crop or by erosion; thus soil levels can be built up as described.

Table 11.23. Amount of Phosphorus (P_2O_5) Required to Build Up the Soil (Based on Buildup Occurring over a 4-Year Period; 9 Pounds of P_2O_5 per Acre Required to Change P_1 Soil Test 1 Pound)

P_1 test, lb/acre	Pounds of P_2O_5 to apply per acre *each year* for soils with supplying power rated		
	Low	Medium	High
4	103	92	81
6	99	88	76
8	94	83	72
10	90	79	68
12	86	74	63
14	81	70	58
16	76	65	54
18	72	61	50
20	68	56	45
22	63	52	40
24	58	47	36
26	54	43	32
28	50	38	27
30	45	34	22
32	40	29	18
34	36	25	14
36	32	20	9
38	27	16	4
40	22	11	0
42	18	7	0
44	14	2	0
45	11	0	0
46	9	0	0
48	4	0	0
50	0	0	0

Experience during the past several years indicates that on most soils potassium tends to follow the buildup pattern of phosphorus, but on other soils, soil-test levels do not build up as expected. Because of this, both the buildup-maintenance and the annual application options are provided.

Producers whose soils have one or more of the following conditions should consider the annual application option:

1. Soils for which past records indicate that soil-test potassium does not increase when buildup applications are applied.
2. Sandy soils that do not have a capacity large enough to hold adequate amounts of potassium.
3. Agricultural lands having an unknown or very short tenure arrangement.

On all other fields, use of the buildup-maintenance option is suggested.

Rate of fertilizer application

Buildup. The only significant loss of soil-applied potassium is through crop removal or soil erosion. Therefore, it is recommended that soil-test potassium be built up to values of 260 and 300 pounds of exchangeable potassium, respectively, for soils in the low and high cation-exchange capacity region. These

Table 11.24. Maintenance Fertilizer Required for Various Yields of Crops

Yield, per acre	P_2O_5	K_2O[a]
	----- *pounds per acre* -----	
Corn grain		
90 bu	39	25
100	43	28
110	47	31
120	52	34
130	56	36
140	60	39
150	64	42
160	69	45
170	73	48
180	77	50
190	82	53
200	86	56
Oats		
50 bu	19[b]	10
60	23	12
70	27	14
80	30	16
90	34	18
100	38	20
110	42	22
120	46	24
130	49	26
140	53	28
150	57	30
Soybeans		
30 bu	26	39
40	34	52
50	42	65
60	51	78
70	60	91
80	68	104
90	76	117
100	85	130
Corn silage		
90 bu; 18 tons	48	126
100; 20	53	140
110; 22	58	154
120; 24	64	168
130; 26	69	182
140; 28	74	196
150; 30	80	210
Wheat		
30 bu	27[b]	9
40	36	12
50	45	15
60	54	18
70	63	21
80	72	24
90	81	27
100	90	30
110	99	33
Alfalfa, grass, or alfalfa-grass mixtures		
2 tons	24	100
3	36	150
4	48	200
5	60	250
6	72	300
7	84	350
8	96	400
9	108	450
10	120	500

[a] If the annual application option is chosen, then K application will be 1.5 times the values shown.
[b] Values given are 1.5 times actual removal.

values are slightly higher than that required for maximum yield, but as in the recommendations for phosphorus, this will ensure that potassium availability will not limit crop yields (Figure 11.15).

Research has shown that 4 pounds of K_2O are required, on the average, to increase the soil test by 1 pound. Therefore, the recommended rate of potassium application for increasing the soil-test value to the desired goal is equal to four times the difference between the soil-test goal and the actual value of the soil test.

Tests on soil samples that are taken before May 1 or after September 30 should be adjusted downward as follows: subtract 30 for the dark-colored soils in central and northern Illinois; subtract 45 for the light-colored soils in central and northern Illinois, and fine-textured bottomland soils; and subtract 60 for the medium- and light-colored soils in southern Illinois. Annual buildup rates of potassium application recommended for a 4-year period for various soil test values are presented in Table 11.25.

Table 11.25. Amount of Potassium (K_2O) Required to Build Up the Soil (Based on the Buildup Occurring over a 4-Year Period; 4 Pounds of K_2O per Acre Required to Change the K Test 1 Pound)

K test[a], pounds per acre	Amount of K_2O to apply per acre *each year* for soils with cation-exchange capacity: Low[b]	High[b]
50	210	250
60	200	240
70	190	230
80	180	220
90	170	210
100	160	200
110	150	190
120	140	180
130	130	170
140	120	160
150	110	150
160	100	140
170	90	130
180	80	120
190	70	110
200	60	100
210	50	90
220	40	80
230	30	70
240	20	60
250	10	50
260	0	40
270	0	30
280	0	20
290	0	10
300	0	0

[a] Tests on soil samples that are taken before May 1 or after September 30 should be adjusted downward as follows: subtract 30 pounds for dark-colored soils in central and northern Illinois; 45 pounds for light-colored soils in central and northern Illinois, and fine-textured bottomland soils; and 60 pounds for medium- and light-colored soils in southern Illinois.
[b] Low cation-exchange capacity soils are those with CEC less than 12 me/100 g soil; high capacity soils are those with CEC at least 12 me/100 g soil.

Wheat is not very responsive to potassium unless the soil test value is less than 100. Because wheat is usually grown in rotation with corn and soybeans, it is suggested that the soils be maintained at the optimum available potassium level for corn and soybeans.

Maintenance. As with phosphorus, the amount of fertilizer required to maintain the soil-test value equals the amount removed by the harvested portion of the crop (Table 11.24).

Annual application option. If soil-test levels are below the desired buildup goal, apply potassium fertilizer annually at an amount equivalent to 1.5 times the potassium content in the harvested portion of the expected yield. If levels are only slightly below desired buildup levels, so that buildup and maintenance are less than 1.5 times removal, add the lesser amount. Continue to monitor the soil-test potassium level every 4 years.

If soil-test levels are within a range from the desired goal to 100 pounds above the desired potassium goal, apply enough potassium fertilizer to replace what the harvested yield will remove.

Each of the proposed options (buildup-maintenance and annual) has advantages and disadvantages. In the short run, the annual option will likely be less costly. In the long run, the buildup approach may be more economical. In years of high income, tax benefits may be obtained by applying high rates of fertilizer. Also, in periods of low fertilizer prices, the soil can be built to higher levels that in essence bank the materials in the soil for use at a later date when the economy may not be as good for fertilizer purchases. Producers using the buildup system are insured against yield loss that may occur in years when weather conditions prevent fertilizer application or in years when fertilizer supplies are not adequate. The primary advantage of the buildup concept is the slightly lower risk of potential yield reduction that may result from lower annual fertilizer rates. This is especially true in years of exceptionally favorable growing conditions. The primary disadvantage of the buildup option is the high cost of fertilizer in the initial buildup years.

Examples of how to figure phosphorus and potassium fertilizer recommendations follow.

Example 1. Continuous corn with a yield goal of 140 bushels per acre:

(a)

Soil-test results	*Soil region*
P_1 30	high
K 250	high

(b) *Fertilizer recommendation, pounds per acre per year*

	P_2O_5	K_2O
Buildup	22 (Table 10.19)	50 (Table 10.21)
Maintenance	60 (Table 10.20)	39 (Table 10.20)
Total	82	89

Example 2. Corn-soybean rotation with a yield goal of 140 bushels per acre for corn and 40 bushels per acre for soybeans:

(a) *Soil-test results* / *Soil region*

Soil-test results	Soil region
P_1 20	low
K 200	low

(b) *Fertilizer recommendation, pounds per acre per year*

	P_2O_5	K_2O
Corn		
Buildup	68	60
Maintenance	60	39
Total	128	99
Soybeans		
Buildup	68	60
Maintenance	34	52
Total	102	112

Note that buildup recommendations are independent of the crop to be grown, but maintenance recommendations are directly related to the crop to be grown and the yield goal for the particular crop.

Example 3. Continuous corn with a yield goal of 150 bushels per acre:

(a) *Soil-test results* / *Soil region*

Soil-test results	Soil region
P_1 90	low
K 420	low

(b) *Fertilizer recommendation, pounds per acre per year*

	P_2O_5	K_2O
Buildup	0	0
Maintenance	0	0
Total	0	0

Note that soil-test values are higher than those suggested; thus no fertilizer is recommended. Retest the soil after 4 years to determine fertility needs.

Example 4. Corn-soybean rotation with a yield goal of 120 bushels per acre for corn and 35 bushels per acre for soybeans:

(a) *Soil-test results* / *Soil region*

Soil-test results	Soil region
P_1 20	low
K 180	low (soil test does not increase as expected)

(b) *Fertilizer recommendation, pounds per acre per year*

	P_2O_5	K_2O
Corn		
Buildup	68	. . .
Maintenance	52	. . .
Total	120	51 (34 x 1.5)
Soybeans		
Buildup	68	. . .
Maintenance	30	. . .
Total	98	69 (46 x 1.5)

For farmers planning to double-crop soybeans after wheat, it is suggested that phosphorus and potassium fertilizer required for both the wheat and soybeans be applied before seeding the wheat. This practice will reduce the number of field operations necessary at planting time and will hasten the planting operation.

The maintenance recommendations for phosphorus and potassium in a double-crop wheat and soybean system are presented in Table 11.26 and Table 11.27, respectively. Assuming a wheat yield of 50 bushels per acre followed by a soybean yield of 30 bushels per acre, the maintenance recommendation would be 71 pounds of P_2O_5 and 54 pounds of K_2O per acre.

Computerized recommendations

Soil fertility recommendations have been incorporated into a microcomputer program that utilizes the soil-test information, soil type and characteristics, cropping and management history, cropping plans, and yield goals to develop recommendations for lime, nitrogen, phosphorus, and potassium. This program, called *Soil Plan*, groups together similar fertilizer recommendations and provides a map showing where each recommendation should be implemented within the field. Users have the option of altering the map to adjust to the kind of spread pattern desired. Additionally, the program will indicate the potential impact of altering the recommendation on crop yield.

Table 11.26. Maintenance Phosphorus Required for Wheat-Soybean Double-Crop System

Wheat yield, bu/acre	Soybean yield, bu/acre				
	20	30	40	50	60
	P_2O_5, lb/acre				
30	44	53	61	69	78
40	53	62	70	78	87
50	62	71	79	87	96
60	71	80	88	96	105
70	80	89	97	105	114
80	89	98	106	114	123

Table 11.27. Maintenance Potassium Required for Wheat-Soybean Double-Crop System

Wheat yield, bu/acre	Soybean yield, bu/acre				
	20	30	40	50	60
	K_2O, lb/acre				
30	35	48	61	74	87
40	38	51	64	77	90
50	41	54	67	80	93
60	44	57	70	83	96
70	47	60	73	86	99
80	50	63	76	89	102

Further information about this program may be obtained from Illinet Software, 548 Bevier Hall, 905 S. Goodwin Avenue, Urbana, IL 61801.

Time of application

Although the fertilizer rates for buildup and maintenance in Table 11.23 through Table 11.25 are for an annual application, producers may apply enough nutrients in any 1 year to meet the needs of the crops to be grown in the succeeding 2- to 3-year period.

Phosphorus and potassium fertilizers may be applied in the fall to fields that will not be fall-tilled, provided that the slope is less than 5 percent. Do not fall-apply fertilizer to fields that are subject to rapid runoff. When the probability of runoff loss is low, soybean stubble need not be tilled solely for the purpose of incorporating fertilizer. This statement holds true when ammoniated phosphate materials are used as well because the potential for volatilization of nitrogen from ammoniated phosphate materials is insignificant.

For perennial forage crops, broadcast and incorporate all of the buildup and as much of the maintenance phosphorus as economically feasible before seeding. On soils with low fertility, apply 30 pounds of phosphate (P_2O_5) per acre using a band seeder. If a band seeder is used, you may safely apply a maximum of 30 to 40 pounds of potash (K_2O) per acre in the band with the phosphorus. Up to 600 pounds of K_2O per acre can be safely broadcast in the seedbed without damaging seedlings.

Applications of phosphorus and potassium topdressed on perennial forage crops may be made at any convenient time. Usually this will be after the first harvest or in September.

High water-solubility of phosphorus

The water-solubility of the P_2O_5 listed as available on the fertilizer label is of little importance under typical field crop and soil conditions on soils with medium to high levels of available phosphorus, when recommended rates of application and broadcast placement are used.

For some situations, water-solubility is important. These situations include the following:

1. For band placement of a small amount of fertilizer to stimulate early growth, at least 40 percent of the phosphorus should be water-soluble for application to acidic soils and, preferably, 80 percent for calcareous soils. As shown in Table 11.28, the phosphorus in nearly all fertilizers commonly sold in Illinois is highly water-soluble. Phosphate water-solubility in excess of 80 percent has not been shown to give further yield increases above those that have water-solubility levels of at least 50 percent.
2. For calcareous soils, a high degree of solubility in water is desirable, especially on soils that are shown by soil test to be low in available phosphorus.

Table 11.28. Characteristics of Some Common Processed-Phosphate Materials

Material	Percent P_2O_5	Percent water-soluble	Percent citrate-soluble	Total pct. available
Ordinary superphosphate 0-20-0	16-22	78	18	96
Triple superphosphate	44-47	84	13	97
Mono-ammonium phosphate 11-48-0	46-48	100	...	100
Diammonium phosphate 18-46-0	46	100	...	100
Ammonium polyphosphate 10-34-0, 11-37-0	34-37	100	...	100

Secondary nutrients

The elements that are classified as secondary nutrients include calcium, magnesium, and sulfur. Crop yield response to application of these three nutrients has been observed on a very limited basis in Illinois. Therefore, the data base necessary to correlate and calibrate soil-test procedures is limited, and thus the reliability of the suggested soil-test levels for the secondary nutrients presented in Table 11.29 is low.

Deficiency of calcium has not been recognized in Illinois where soil pH is 5.5 or above. Calcium deficiency associated with acidic soils should be corrected by the use of limestone that is adequate to correct the soil pH.

Magnesium deficiency has been recognized in isolated situations in Illinois. Although the deficiency is usually associated with acidic soils, in some instances low magnesium has been reported on sandy soils that were not excessively acidic. The soils most likely to be deficient in magnesium include sandy soils throughout Illinois and low exchange-capacity soils of southern Illinois. Deficiency will be more likely where calcitic rather than dolomitic limestone has been used and where potassium test levels have been high (greater than 400).

Recognition of sulfur deficiency has been reported with increasing frequency throughout the Midwest. These deficiencies probably are occurring because of (1) increased use of S-free fertilizer; (2) decreased use of sulfur as a fungicide and insecticide; (3) increased crop yields, resulting in increased requirements for all of the essential plant nutrients; and (4) decreased atmospheric sulfur supply. Early season S symptoms

Table 11.29. Suggested Soil-Test Levels for the Secondary Nutrients

Soil type	Levels that are adequate for crop production: Calcium	Magnesium	Rating	Sulfur
	----- pounds per acre -----			*lb/acre*
Sandy	400	60-75	Very low	0-12
Silt loam	800	150-200	Low	12-22
			Response unlikely	22

may disappear as rainfall contributes some S and as root systems develop to exploit greater soil volume.

Organic matter is the primary source of sulfur in soils. Thus soils low in organic matter are more likely to be deficient than are soils with a high level of organic matter. Because sulfur is very mobile and can be readily leached, deficiency is more likely to be found on sandy soils than on finer-textured soils.

A yield response to sulfur application was observed at 5 of 85 locations in Illinois (Table 11.30). Two of these responding sites, one an eroded silt loam and one a sandy soil, were found in northwestern Illinois (Whiteside and Lee counties); one site, a silty clay loam, was in central Illinois (Sangamon County); and two sites, one a silt loam and one a sandy loam, were in southern Illinois (Richland and White counties).

At the responding sites, sulfur treatments resulted in corn yields that averaged 11.2 bushels per acre more than yields from the untreated plots. At the nonresponding sites, yields from the sulfur-treated plots averaged only 0.6 bushel per acre more than those from the untreated plots (Table 11.30). If only the responding sites are considered, the sulfur soil test predicts with good reliability which sites will respond to sulfur applications. Of the five responding sites, one had only 12 pounds of sulfur per acre, less than the amount considered necessary for normal plant growth, and three had marginal sulfur concentration (from 12 to 20 pounds of sulfur per acre). Sulfur tests on the 80 nonresponding sites showed 14 to be deficient and 29 to have a level of sulfur that is considered marginal for normal plant growth. Sulfur applications, however, produced no significant positive response in these plots. The correlation between yield increases and measured sulfur levels in the soil was very low, indicating that the sulfur soil test did not reliably predict sulfur need.

Experiments were conducted over a 2-year period on a Cisne silt loam and a Grantsburg silt loam in southern Illinois to evaluate the effect of sulfur application on wheat production. Even though increasing rates of sulfur application caused an increase in the sulfur concentration of the flag leaf and the whole plant, it did not increase grain yield at either location in either year. Based on these 2 years of study, routine application of sulfur fertilizer for wheat production does not appear warranted.

In addition to soil-test values, one should also consider organic-matter level, potential atmospheric sulfur contributions, subsoil sulfur content, and moisture conditions just before soil sampling in determining whether a sulfur response is likely. If organic-matter levels are greater than 2.5 percent or if the field in question is located in an area downwind from industrial operations where significant amounts of sulfur are being emitted, use sulfur only on a trial basis even when the soil-test reading is low. Because sulfur is a mobile nutrient supplied principally by organic-matter oxidation, abnormal precipitation (either high or low) could adversely affect the sulfur status of samples taken from the soil surface. If precipitation has been high just before sampling, some samples may have a low reading due to leaching. If precipitation were low and temperatures warm, some soils might have a high reading when, in fact, the soil is not capable of supplying adequate amounts of sulfur throughout the growing season.

Micronutrients

The elements that are classified as essential micronutrients include zinc, iron, manganese, copper, boron, molybdenum, and chlorine. These nutrients are classified as micronutrients because they are required in small (micro) amounts. Confirmed deficiencies of these micronutrients in Illinois have been limited to boron deficiency of alfalfa, zinc deficiency of corn, and iron and manganese deficiencies of soybeans.

Similar to the tests for secondary nutrients, the reliability and usefulness of micronutrient tests are very low because of the limited data base available to correlate and calibrate the tests. Suggested levels for each of the tests are provided in Table 11.31. In most cases, use of plant analysis will probably provide a better estimate of micronutrient needs than will the soil test.

Manganese deficiency (stunted plants with green veins in yellow or whitish leaves) is common on high-pH (alkaline), sandy soils, especially during cool, wet weather in late May and June. Suggested treatment is to spray either manganese sulfate or an organic man-

Table 11.30. Average Yields at Responding and Nonresponding Zinc and Sulfur Test Sites, 1977-79

	Number of sites	Yield from untreated plots	Yield from zinc-treated plots	Yield from sulfur-treated plots
		bushels per acre		
Responding sites				
Low-sulfur soil	5	140.0	...	151.2
Low-zinc soil	3	150.6	164.7	...
Nonresponding sites	80	147.6	146.2	148.2

Table 11.31. Suggested Soil-Test Levels for Micronutrients

Micronutrient and procedure	Soil-test level		
	Very low	Low	Adequate
	pounds per acre		
Boron (hot-water soluble)	0.5	1	2
Iron (DTPA)	...	<4	>4
Manganese (DTPA)	...	<2	>2
Manganese (H_3PO_4)	...	<10	>10
Zinc (.1N HCl)	...	<7	>7
Zinc (DTPA)	...	<1	>1

ganese formulation onto the leaves soon after the symptoms first appear; use the rate suggested by the manufacturer. Broadcast application on the soil is ineffective because the manganese becomes unavailable in soils with a high pH.

Wayne and Hark soybean varieties or lines developed from them often show iron deficiency on soils with a very high pH (usually 7.4 to 8.0). The symptoms are similar to those shown with manganese deficiency. Most of the observed deficiencies have been on Harpster, a "shelly" soil that occurs in low spots in some fields in central and northern Illinois. This problem has appeared on Illinois farms only since the Wayne variety was introduced in 1964.

Soybeans often outgrow the stunted, yellow appearance of iron shortage. As a result, it has been difficult to measure yield losses or decide whether or how to treat affected areas. Sampling by U.S. Department of Agriculture scientists indicated yield reductions of 30 to 50 percent in the center of severely affected spots. The yield loss may have been caused by other soil factors associated with a very high pH and poor drainage, rather than by iron deficiency itself. Several iron treatments were ineffective in trials near Champaign and DeKalb.

Research in Minnesota has shown that time of iron application is critical if a response is to be attained. Researchers recommend that a rate of 0.15 pound of iron per acre as iron chelate be applied to leaves within 3 to 7 days after chlorosis symptoms develop (usually in the second-trifoliate stage of growth). Waiting for soybeans to grow to the fourth- or fifth-trifoliate stage before applying iron resulted in no yield increase. Because iron applied to the soil surface between rows does not help, applications directed over the soybean plants were preferred.

A significant yield response to zinc applications was observed at 3 of 85 sites evaluated in Illinois (Table 11.30). The use of zinc at the responding sites produced a corn yield that averaged 14.1 bushels per acre more than the check plots. Two sites were Fayette silt loams in Whiteside County, and one was a Greenriver sand in Lee County.

At two of the three responding sites, tests showed that the soil was low or marginal in available zinc. The soil of the third had a very high zinc level but was deficient in available zinc, probably because of the excessively high phosphorus level also found at that site.

The zinc soil-test procedures accurately predicted results for two-thirds of the responding sites. The same tests, however, incorrectly predicted that 19 other sites would also respond. These results suggest that the soil test for available zinc can indicate where zinc deficiencies are found but does not indicate reliably whether the addition of zinc will increase yields.

To identify areas before micronutrient deficiencies become important, continually observe the most sensitive crops in soil situations in which the elements are likely to be deficient (Table 11.32).

In general, deficiencies of most micronutrients are accentuated by one of five situations: (1) strongly weathered soils; (2) coarse-textured soils; (3) high-pH soils; (4) organic soils; and (5) soils that are inherently low in organic matter or low in organic matter because erosion or land-shaping processes have removed the topsoil.

The use of micronutrient fertilizers should be limited to the application of specific micronutrients to areas of known deficiency. Only the deficient nutrient should be applied. An exception to this guideline would be situations in which farmers already in the highest yield bracket try micronutrients on an experimental basis in fields that are yielding less than would be expected under good management, which includes an adequate nitrogen, phosphorus, and potassium fertility program and a favorable pH.

Method of fertilizer application

With the advent of new equipment, producers have a number of options for placement of fertilizers. These options range from traditional broadcast application to injection of the materials at varying depths in the soil. Selection of the proper application technique for a particular field will depend at least in part upon the inherent fertility level, the crop to be grown, the land tenure, and the tillage system.

On fields where the fertility level is at or above the desired goal, there is little research evidence to show any significant difference in yield that is associated with method of application. In contrast, on low-testing soils and in soils that "fix" phosphorus, placement of the fertilizer within a concentrated band has been shown to result in higher yields, particularly at low rates of application. On higher-testing soils, plant recovery of applied fertilizer in the year of application will usually be greater from a band than a broadcast application, though yield differences are unlikely.

Broadcast fertilization. On highly fertile soils, both maintenance and buildup phosphorus and potassium will be efficiently utilized when broadcast and then plowed or disked in. This system, particularly when the tillage system includes a moldboard plow every few years, distributes nutrients uniformly throughout the entire plow depth. As a result, roots growing within that zone have access to high levels of fertility. Because the nutrients are intimately mixed with a large volume of soil, opportunity exists for increased nutrient fixation on soils having a high fixation ability. Fortunately, most Illinois soils do not have high fixation rates for phosphorus or potassium.

Row fertilization. On soils of low fertility, placement of fertilizer in a concentrated band below and to the side of the seed has been shown to be an efficient method of application, especially in situations for which the rate of application is markedly less than that needed to build the soil to the desired level. Producers who are not assured of having long-term

Table 11.32. Soil Situations and Crops Susceptible to Micronutrient Deficiency

Micronutrient	Sensitive crop	Susceptible soil situations	Season favoring deficiency
Zinc (Zn)	Young corn	1. Low in organic matter, either inherently or because of erosion or land shaping 2. High pH, that is, >7.3 3. Very high phosphorus 4. Restricted root zone 5. Coarse-textured (sandy) soils 6. Organic soils	Cool, wet
Iron (Fe)	Wayne soybeans, grain sorghum	High pH	Cool, wet
Manganese (Mn)	Soybeans, oats	1. High pH 2. Restricted root zone 3. Organic soils	Cool, wet
Boron (B)	Alfalfa	1. Low organic matter 2. High pH 3. Strongly weathered soils in south-central Illinois 4. Coarse-textured (sandy) soils	Drought
Copper (Cu)	Corn, wheat	1. Infertile sand 2. Organic soils	Unknown
Molybdenum (Mo)	Soybeans	Strongly weathered soils in south-central Illinois	Unknown
Chlorine (Cl)	Unknown	Coarse-textured soils	Excessive leaching by low-Cl water

tenure on the land may wish to consider this option. The major disadvantages of this technique are (1) the additional time and labor required at planting time; (2) limited contact between roots and fertilizer; and (3) inadequate rate of application to increase soil levels for future crops.

For information on the use of starter fertilizer for no-till, see the subsection about fertilizer management related to tillage systems.

Strip application. With this technique, phosphorus, potassium, or both are applied in narrow bands on approximately 30-inch centers on the soil surface, in the same direction as the primary tillage. The theory behind this technique is that, after moldboard plowing, the fertilizer will be distributed in a narrow vertical band throughout the plow zone. Use of this system reduces the amount of soil-to-fertilizer contact as compared with a broadcast application, and thus it reduces the potential for nutrient fixation. Because the fertilizer is distributed through a larger soil volume than with a band application, the opportunity for root-fertilizer contact is greater.

Deep fertilizer placement. Several terms have been used to define this technique. They include root-zone banding, dual placement, knife injection, and deep placement. With this system a mixture of nitrogen-phosphorus or nitrogen-phosphorus-potassium is injected at a depth ranging from 4 to 8 inches. The knife spacings used may vary by crop to be grown, but generally they are 15 to 18 inches apart for close-grown crops such as wheat and 30 inches for row crops. Use of this technique provided a significantly higher wheat yield as compared with a broadcast application of the same rate of nutrients in some, but not all, experiments conducted in Kansas. Wisconsin research showed the effect of this technique to be equivalent to that of a band application for corn on a soil testing high in phosphorus but inferior to that of a band application for corn on a soil testing low in phosphorus. If this system is used on low-testing soils, it is advisable to apply a portion of the phosphorus fertilizer in a band with the planter.

Dribble fertilizer. This technique involves the application of urea-ammonium nitrate solutions in concentrated bands on 30-inch spacings on the soil surface. Results from several states have shown that this system reduces the potential for nitrogen loss of these materials, as compared with an unincorporated broadcast application. However, it has not been shown to be superior to an injected or an incorporated application of urea-ammonium nitrate solution.

"Pop-up" fertilization. The term "pop-up" is a misnomer. The corn does not emerge sooner than it does without this kind of application, and it may come up 1 or 2 days later. The corn may, however, grow more rapidly during the first 1 to 2 weeks after emergence. Pop-up fertilizer will make corn look very good early in the season and may aid in early cultivation for weed control. But no substantial difference in yield is likely in most years due to a pop-up application as compared to fertilizer that is placed in a band to the side and below the seed. Seldom will there be a difference of more than a few days in the time the root system intercepts fertilizer placed with the seed as compared to that placed below and to the side of the seed.

If used, pop-up fertilizer should contain all three major nutrients in a ratio of about 1-4-2 of N-P_2O_5-

K_2O (1-1.7-1.7 of N-P-K). Under normal moisture conditions, the maximum safe amount of N plus K_2O for pop-up placement is about 10 or 12 pounds per acre in 40-inch rows and correspondingly more in 30- and 20-inch rows. In excessively dry springs, even these low rates may result in damage to seedlings, reduction in germination, or both. Pop-up fertilizer is unsafe for soybeans. In research conducted at Dixon Springs, a stand was reduced to one-half by applying 50 pounds of 7-28-14 and reduced to one-fifth with 100 pounds of 7-28-14.

Site-specific application. Equipment has recently been developed that uses computer technology to alter the rate of fertilizer application as the truck passes across the field. Although this technology and the supporting research are still in their infancy, this approach offers the potential to improve yield while minimizing the potential for overfertilization. Yield improvement will result from applying the correct rate (not a rate based on average soil test) to the low-testing portions of the field. Overfertilization will be reduced by applying the correct rate (in many cases this may be zero) to high-testing areas of the field. The combination of improved yield and reduced output will result in improved profit.

Foliar fertilization. Researchers have known for many years that plant leaves absorb and utilize nutrients sprayed on them. Foliar fertilization has been used successfully for certain crops and nutrients. This method of application has had the greatest use with nutrients required in only small amounts by plants. Nutrients required in large amounts, such as nitrogen, phosphorus, and potassium, have usually been applied to the soil rather than the foliage.

The possible benefit of foliar-applied nitrogen fertilizer was researched at the University of Illinois in the 1950s. Foliar-applied nitrogen increased corn and wheat yield, provided that the soil was deficient in nitrogen. Where adequate nitrogen was applied to the soil, additional yield increases were not obtained from foliar fertilization.

Additional research in Illinois was conducted on foliar application of nitrogen to soybeans in the 1960s. This effort was an attempt to supply additional nitrogen to soybeans without decreasing nitrogen that was symbiotically fixed. That is, it was thought that if nitrogen application were delayed until after nodules were well established, then perhaps symbiotic fixation would remain active. Single or multiple applications of nitrogen solution to foliage did not increase soybean yields. Damage to vegetation occurred in some cases because of leaf "burn" caused by the nitrogen fertilizer.

Although considerable research in foliar fertilization had been conducted in Illinois already, new research was conducted in 1976 and 1977. This new research was prompted by a report from a neighboring state indicating that soybean yields had recently been increased by as much as 20 bushels per acre in some trials. Research in that state differed from earlier work on soybeans in that, in addition to nitrogen, the foliar fertilizer increased yield only if phosphorus, potassium, and sulfur were also included. Researchers there thought that soybean leaves become deficient in nutrients as nutrients are translocated from vegetative parts to the grain during grain development. They reasoned that foliar fertilization, which would prevent leaf deficiencies, should result in increased photosynthesis that would be expressed in higher grain yields.

Foliar fertilization research was conducted at several locations in Illinois during 1976 and 1977 — ranging from Dixon Springs in southern Illinois to DeKalb in northern Illinois. None of the experiments gave economical yield increases. In some cases there were yield reductions, which were attributed to leaf damage caused by the fertilizer. Table 11.33 contains data from a study at Urbana in which soybeans were sprayed four times with various fertilizer solutions. Yields were not increased by foliar fertilization.

Nontraditional products

In this day of better informed farmers, it seems hard to believe that the number of letters, calls, and promotional leaflets about nontraditional products is increasing. The claim made is usually that "Product X" either replaces fertilizers and costs less, makes nutrients in the soil more available, supplies micronutrients, or is a natural product that does not contain strong acids that kill soil bacteria and earthworms.

The strongest position that legitimate fertilizer dealers, Extension advisers, and agronomists can take is to challenge these peddlers to produce unbiased research results in support of their claims. Testimonials by farmers are no substitute for research.

Extension specialists at the University of Illinois are ready to give unbiased advice when asked about purchasing new products or accepting a sales agency for them.

In addition, each Extension office has the publication *Compendium of Research Reports on the Use of Nontraditional Materials for Crop Production*, which contains data on a number of nontraditional products that have been tested in the Midwest. Check with the nearest Extension office for this information.

Table 11.33. Yields of Corsoy and Amsoy Soybeans After Fertilizer Treatments Were Sprayed on the Foliage Four Times, Urbana

Treatment per spraying, lb/acre				Yield, bu/acre	
N	P_2O_5	K_2O	S	Corsoy	Amsoy
0	0	0	0	61	56
20	0	0	0	54	53
0	5	8	1	58	56
10	5	8	1	56	58
20	5	8	1	55	52
30	7.5	12	1.5	52	46

Chapter 12.

Soil Management and Tillage Systems

Soils are a natural resource. In Illinois, the greatest concern for soil degradation is soil erosion due to water. The potential for soil erosion of a specific soil type, slope, and slope length largely depends on the crops grown and the number and types of tillage operations used to produce the crops. Several techniques are available to reduce soil erosion, including residue management, crop rotation, contouring, grass waterways, terraces, and conservation structures. The techniques adopted must ensure the long-term productivity of the land, be environmentally sound, and, of course, be profitable. Residue management, consisting of mulch tillage and no-tillage farming systems, is recognized as a cost-effective means of significantly reducing soil erosion and maintaining productivity.

Conservation compliance

A dramatic step taken to encourage the adoption of techniques to control soil erosion was the passage of the 1985 Food Security Act. Conservation requirements were also included in the 1990 Farm Bill. Conservation compliance is a major provision of the federal legislation. The goal is to reduce soil erosion to levels that will maintain the long-term productivity of the land. For farmers to remain eligible for many USDA programs, conservation compliance provisions of the laws required farmers to develop and apply an approved conservation plan on their highly erodible fields. Conservation plans must meet specifications of the local Soil Conservation Service and must be approved by the local conservation district. Most conservation compliance plans include use of mulch tillage or no-tillage. Even though conservation compliance pertains only to highly erodible fields, many farmers are adopting conservation tillage systems, not only to reduce soil erosion, but because it reduces labor and equipment costs and can be more profitable.

Conservation compliance provisions of the 1985 Food Security Act focus on reducing soil erosion. There are growing concerns about water quality, likely to be an issue in hammering out future state and federal legislation. Many conservation practices help preserve water quality. Conservation tillage, terraces, strip cropping, contouring, grass waterways, and filter strips all reduce water runoff and soil erosion and, thus, help preserve water quality.

As indicated above, the tillage system selected to produce a crop has a significant effect on soil erosion, water quality, and profitability. Profitability, of course, is determined from crop yield (net income) and costs. Therefore, selecting a tillage system is an important management decision. Before discussing the factors in detail, several tillage systems will be defined.

Conservation tillage systems

The objective of conservation tillage is to provide a means of profitable crop production while minimizing soil erosion due to wind and water. The emphasis is on soil conservation, but the conservation of soil moisture, energy, labor, and even equipment are additional benefits. To be considered conservation tillage, the system must produce — or there must be present in soil — conditions that resist erosion by wind, rain, and flowing water. Such resistance is achieved either by protecting the soil surface with crop residues or growing plants, or by increasing the surface roughness or soil permeability.

Conservation tillage is often defined as any crop production system that provides either (1) a residue cover of at least 30 percent after planting to reduce soil erosion due to water; or (2) at least 1,000 pounds per acre of flat, small-grain residues (or the equivalent) on the soil surface during the critical erosion period to reduce soil erosion due to wind.

The term "conservation tillage" represents a broad spectrum of tillage systems. However, maintaining an effective amount of plant residue on the soil surface is the crucial issue, which is why the Soil Conservation Service (SCS) has replaced conservation tillage with the term "crop residue management." Crop residue management refers to a philosophy of year-round management of residue to maintain the level of cover needed for adequate control of erosion. Adequate control of soil erosion often requires more than 30 percent residue cover after planting.

Conservation tillage or a crop residue management system, depending on the preceding crop, includes a broad spectrum of tillage systems, some of which are described below.

No-tillage system (no-till)

With no-till, the soil is left undisturbed from harvest to seeding and from seeding to harvest. The only "tillage" is the soil disturbance in a narrow band created by row cleaners, coulters, seed furrow openers, or other devices attached to the planter or drill. Many no-till planters are now equipped with devices to clear the row area of residue. No-till planters and drills must be able to cut residue and penetrate undisturbed soil. No-till planting of corn and no-till drilling of soybeans recently have increased rapidly in Illinois.

Strictly speaking, a no-till system does not allow operations that disturb the soil other than the planting or drilling operation. However, the basic no-till system is sometimes modified by the use of a drag harrow, rotary hoe, row-crop cultivator, or knife fertilizer application.

Ridge-till (ridge-plant, till-plant)

With ridge-till, the soil is left undisturbed from harvest to planting except for fertilizer injection. Crops are planted and grown on ridges formed in the previous growing season. Typically, ridges are built and reformed annually at cultivation. Ridges may be formed after harvest when starting a ridge-till system or when wet soil prevents forming ridges at cultivation. Forming ridges after harvest is not recommended because the lack of residue in furrows can allow excessive erosion. Ridge height at harvest should be 6 to 8 inches. To meet erosion control guidelines for highly erodible land (HEL), ridges must be at least 3 inches higher than the furrows after planting.

A planter equipped with sweeps, disk row cleaners, coulters, or horizontal disks is used in most ridge-till systems. These row-cleaning attachments remove 1 to 2 inches of soil, surface residue, and weed seeds from the row area. Ideally, this process leaves a residue-free strip of moist soil on top of a ridge into which the seed is planted. Special row cultivators are used to reform the ridges. Corn and grain sorghum stalks are sometimes shredded between harvest and planting.

Fertilizers may be broadcast in the fall, banded by the planter as a starter, or applied during cultivation. Fertilizers, especially nitrogen (N), can be knifed into the soil in the fall or spring.

In one variation of ridge-till, planting is preceded by a very shallow tillage or strip tillage operation that destroys early season weeds, flattens ridge tops, and clears residue from ridges, but leaves most of the ridge in place. Implements for shallow tillage include harrows, rotary tillers, mulch treaders, and rolling stalk choppers. A conventional planter can be used with this variation of ridge-till.

Mulch-till

Mulch-till includes any conservation tillage system other than no-till and ridge-till. Deep tillage might be performed with a subsoiler or chisel plow; tillage before planting might include one or more passes with a disk harrow, field cultivator, or combination tool. Herbicides or crop cultivation, or both together, control weeds. The tillage tools must be equipped, adjusted, and operated to assure that adequate residue cover remains for erosion control; and the number of operations must be limited. At least 30 percent of the soil surface must be covered with plant residue after planting.

Other tillage systems

Conventional tillage

Conventional tillage is the sequence of tillage operations traditionally or most commonly used in a given geographic area to produce a given crop. The operations used vary considerably for different crops and from one region to another. In the past, conventional tillage in Illinois included moldboard plowing, usually in the fall. Spring operations included one or more disk harrowings or field cultivations before planting or drilling. The soil surface with conventional tillage was essentially free of plant residue and provided a high potential for soil erosion. The term "clean tillage" is also used for any system that provides a residue-free soil surface. A soil surface essentially free of residues can also be achieved with other implements, especially following a crop such as soybeans that produces fragile, easy-to-cover residue.

Systems named by major implement

Several tillage systems are named according to the major implement used in the system. Some examples are moldboard plow, chisel plow, subsoiler, disk, and field cultivator. These systems may be "mulch tillage" systems if at least 30 percent of the soil surface is covered with residue after planting. With these systems, herbicides are often incorporated into the soil before planting using a disk harrow, field cultivator,

or combination tool. No-till attachments are not needed on the planter or drill. Crops planted in rows are usually cultivated.

Minimum tillage

The term "minimum tillage" is not very meaningful, but the term is still used by some. A definition of the term minimum tillage is: The minimum soil manipulation necessary for crop production or meeting tillage requirements under existing conditions. When most people use the term minimum tillage, they mean reduced tillage as defined below.

Reduced tillage

"Reduced tillage" refers to any system that is less intensive and aggressive than conventional tillage. Compared to conventional tillage, the number of operations is decreased, or a tillage implement that requires less energy per unit area is used to replace an implement typically used in the conventional tillage system. The term is sometimes used to mean the same as conservation tillage as defined above. However, to be considered a conservation tillage system, 30 percent of the soil surface must be covered with residue after planting. Because it is not specific, the term reduced tillage is criticized as vague.

Rotary-till system

For the rotary-till system, a powered rotary tiller is used in the fall or spring before planting. The planter may be attached directly to the rotary tiller.

Effects of tillage on soil erosion

A primary advantage of conservation tillage systems, particularly the no-till system, is less soil erosion due to water on sloping soils. Although wind erosion in Illinois is not as great a problem as water erosion, conservation tillage systems also essentially eliminate wind erosion. A bare, smooth soil surface is extremely susceptible to erosion. Many Illinois soils have subsurface layers that are not favorable for root growth and development. Soil erosion slowly but constantly removes the topsoil that is most favorable for root development, resulting in gradually decreasing soil productivity and value. Even on soils without root-restricting subsoils, erosion removes nutrients that must be replaced with additional fertilizers to maintain yields.

An additional problem related to soil erosion is sedimentation and the nutrients, pesticides, and other materials carried by the sediment and water. Sediment and other materials from eroding fields increase water pollution, reduce storage capacity of lakes and reservoirs, and decrease the effectiveness of drainage systems.

Surface residues effectively reduce soil erosion. A residue cover after planting of 20 to 30 percent reduces soil erosion by approximately 50 percent compared to a bare field. A residue cover of 70 percent after planting reduces soil erosion more than 90 percent compared to a bare field. On long steep slopes, conservation tillage will not adequately control soil erosion. Therefore, other practices are required, including contouring, grass waterways, terraces, or structures. For technical assistance in developing erosion control systems, consult your district conservationist or the Soil Conservation Service.

Residue cover

The percentage of the soil surface covered with residues after planting is affected by the previous crop grown and the tillage system used. In general, the higher the crop yield, the greater the amount of residue produced. More important, however, is the type of residue a crop produces. Types of residue produced by various crops have been classified as nonfragile or fragile (Table 12.01). The classification is subjective and based on the ease with which the residues are decomposed by the elements or buried by tillage operations. Plant characteristics such as composition and size of leaves and stems, density of the residues, and relative quantities produced were considered. The residues of a crop such as soybeans are considered fragile because essentially all of the residues are damaged in passing through the combine, the stems and stubble are small in diameter, and the leaves are small and fall from the plants well before harvest. In contrast, corn residues are classified as nonfragile. Cornstalks, leaves, and cobs are individually large in size and

Table 12.01. Types of Residue Produced by Various Crops

Nonfragile	Fragile
Alfalfa or legume hay	Canola/rapeseed
Barley*	Dry beans
Buckwheat	Dry peas
Corn	Fall-seeded cover crops
Flaxseed	Flower seed
Forage seed	Green peas
Forage silage	Potatoes
Grass hay	Soybeans
Millet	Vegetables
Oats*	
Pasture	
Popcorn	
Rye	
Sorghum	
Triticale*	
Wheat*	

NOTE: From *Estimates of Residue Cover Remaining After Single Operation of Selected Tillage Machines*, developed jointly by the Soil Conservation Service, U.S. Department of Agriculture, and the Equipment Manufacturers Institute. First edition, February 1992.

* If a combine is equipped with a straw chipper or the straw is otherwise cut into small pieces, small grain residue should be considered as being fragile.

quite durable, and the total mass of residue produced is greater.

The method often used to measure residue cover is the line-transect method. For the line-transect method, a light rope or tape with 100 equally spaced knots or marks is stretched diagonally across the crop rows. Residue cover is measured by counting each knot or mark that is directly over a piece of residue. The percent residue cover is equal to the number of knots counted.

Often there is a desire to predict the amount of residue that will be remaining on the soil surface using a particular tillage system. The prediction requires knowledge of the amount of residue cover remaining on the soil surface after each field operation included in the tillage system. Typical percentages of the residue cover remaining after various field operations are given in Table 12.02. The percentages can be used to obtain an estimate of the residue cover after each field operation in a tillage system.

A corn crop of 150 bushels per acre will usually provide a residue cover of 95 percent after harvest. Grain sorghum, most small grains, and lower yielding corn will generally provide a cover of 80 to 90 percent. Following soybean harvest, 70 to 80 percent cover typically remains. In all cases, the residue must be uniformly spread behind the combine. For a tillage system, a rough approximation of the residue cover remaining after planting can be obtained by multiplying the initial percent residue cover by the values in Table 12.02 of percent cover remaining after each operation. To leave 30 percent or more residue cover following corn, only one or two tillage operations can be performed. To leave 30 percent cover following soybeans essentially requires that the no-tillage system be used.

Table 12.02. Percent Residue Cover Remaining on the Soil Surface After Weathering or Specific Field Operations

	Type of residue	
	Nonfragile	Fragile
	percent of residue remaining	
Climatic effects		
Overwinter weathering:*		
Following summer harvest	70 to 90	65 to 85
Following fall harvest	80 to 95	70 to 80
Field operations		
Moldboard plow	0 to 10	0 to 5
V ripper/subsoiler	70 to 90	60 to 80
Disk-subsoiler	30 to 50	10 to 20
Chisel plow with:		
Straight spike points	60 to 80	40 to 60
Twisted points or shovels	50 to 70	30 to 40
Coulter-chisel plow with:		
Straight spike points	50 to 70	30 to 40
Twisted points or shovels	40 to 60	20 to 30
Offset disk harrow — heavy plowing >10″ spacing	25 to 50	10 to 25
Tandem disk harrow		
Primary cutting >9″ spacing	30 to 60	20 to 40
Finishing 7″ to 9″ spacing	40 to 70	25 to 40
Light disking after harvest	70 to 80	40 to 50
Field cultivator		
As primary tillage operation:		
Sweeps 12″ to 20″	60 to 80	55 to 75
Sweeps or shovels 6″ to 12″	35 to 75	50 to 70
As secondary tillage operation:		
Sweeps 12″ to 20″ (30 to 50 cm) wide	80 to 90	60 to 75
Sweeps or shovels 6″ to 12″ (15 to 30 cm)	70 to 80	50 to 60
Combination finishing tool with:		
Disks, shanks, and leveling attachments	50 to 70	30 to 50
Spring teeth and rolling baskets	70 to 90	50 to 70
Anhydrous ammonia applicator	75 to 85	45 to 70
Drill		
Conventional	80 to 100	60 to 80
No-till	55 to 80	40 to 80
Conventional planter	85 to 95	75 to 85
No-till planters with:		
Ripple coulters	75 to 90	70 to 85
Fluted coulters	65 to 85	55 to 80
Ridge-till planter	40 to 60	20 to 40

NOTE: From *Estimates of Residue Cover Remaining After Single Operation of Selected Tillage Machines*, developed jointly by the Soil Conservation Service, U.S. Department of Agriculture, and the Equipment Manufacturers Institute. First edition, February 1992.

* With long periods of snow cover and frozen conditions, weathering may reduce residue levels only slightly, while in warmer climates, weathering losses may reduce residue levels significantly.

Crop production with conservation tillage

Crop response to various tillage systems is variable both in farmers' fields and experimental plots. The variability is often difficult to explain because so many aspects of crop production are influenced by tillage. Crop germination, emergence, and growth are largely regulated by soil temperature, aeration, and moisture content; nutrient availability to roots; and mechanical impedance to root growth.

Soil temperature

Crop residue on the soil surface insulates the soil from the sun's energy. In most of Illinois, higher soil temperatures than normal are desirable for plant growth in the spring. Later in the season, temperatures cooler than normal are often desirable, but a complete crop canopy at that time restricts the influence of crop residue on soil temperature.

Minimum daily temperatures of the soil surface usually occur between 6 a.m. and 8 a.m., and in spring are often the same or slightly higher with residue cover than without. Maximum daily temperatures of the soil surface occur between 3 p.m. and 5 p.m., and with clean tillage, are 3° to 6°F warmer than those with residue cover.

During May and early June, the reduced soil temperatures caused by a surface mulch have an influence on early plant growth. In northern regions of the state, average daily soil temperatures are often close to the

temperature at which corn grows, and the reduced temperatures caused by surface residues result in slow plant growth. In southern regions of the state, average daily temperatures are usually well above the temperature at which corn grows; reduced temperatures caused by surface residues have little, if any, effect on early corn growth.

The amount of residue influences soil temperature. Residues from corn, wheat, or grass sod maintain cooler soil than residue from soybeans or other crops that produce less residue or residue that decomposes rapidly.

Whether the lower soil temperature and subsequent slower early growth result in lower yields depends largely on weather conditions during the summer. Research shows that lower yields with reduced tillage systems occur most often on poorly drained soils and on all soils in northern Illinois in years not affected by drought. In these situations, soil temperature, corn growth, and yield potential often improve when residues are removed from the row area. Several planter attachments are available for removing residue from the row area. However, on well-drained soils in southern Illinois, reduced soil temperature caused by in-row residues may increase crop growth and yield.

Allelopathy

Allelopathy refers to the toxic effects on a crop due to decaying residue from the same crop or closely related species. Greenhouse studies have shown that toxins and bacteria from decaying residue affect growth of new plants. In the field, it is difficult to separate allelopathic effects from soil temperature effects. The toxic effect is most likely to occur when corn follows corn, rye, or wheat or when wheat follows rye or wheat, and residue is on or near the soil surface near the growing crop. Planter attachments which remove residue from the row area may reduce the toxic effect.

Moisture

When 30 percent or more of the soil surface is covered with residues, generally evaporation is reduced and water infiltration increases, leading to more water stored in sloping soils. More stored water may be advantageous in dry summer periods, but may be disadvantageous at planting time and during early growth — especially on soils with poor internal drainage.

In most years in Illinois, extra water is needed after the crop canopy closes. In Kentucky, evaporation and transpiration were estimated for no-till and moldboard plowed plots. Average annual evaporation was reduced by 5.9 inches with no-till. Thus, it was concluded more water is available for transpiration with no-till, often resulting in higher corn yields.

Soil moisture saved through reduced tillage systems may be important in years with below normal rainfall. In the northern half of Illinois excessive soil moisture in the spring months often reduces crop growth because it slows soil warming and may delay planting. However, on soils where drought stress often occurs during summer months, additional stored moisture leads to higher yields.

Organic matter and aggregation

Soil organic matter tends to stabilize at a certain level for a specific tillage system, because moldboard plowing buries essentially all of the residue and increases oxidation of organic matter. With conservation tillage systems, especially with no-till and ridge-till systems, residue is left on the soil surface where decomposition is slow which then, after several years, causes organic matter in the upper few inches to increase.

Both the amount and distribution of organic matter change with the tillage system (Table 12.03). Compared to moldboard plowing, organic matter with no-till gradually increases near the soil surface and is maintained or increases slightly below a depth of four inches. It is assumed that with mulch tillage systems, organic matter would approach a level between moldboard plow and no-till systems.

Soil density

An increase in soil density is often referred to as soil compaction. Excessive soil compaction restricts plant root growth, impedes drainage, reduces soil aeration, increases injury potential of some herbicides, and reduces uptake of potassium and nitrogen. Untilled soil usually has a greater density than soil that has been tilled. However, after being loosened by tillage, soil density increases due to wetting and drying, wheel traffic, and secondary tillage operations. By harvest time soil density is often about equal to that of an untilled soil. Wheel traffic of heavy equipment such as tractors, combines, or grain carts may cause plant rooting to be limited or redirected with any tillage system.

Table 12.03. Amount and Distribution of Soil Organic Matter with Plow and No-Till Systems[a]

	Sandy loam		Silty clay loam	
Tillage system	Depth, in.	OM, %	Depth, in.	OM, %
Plow	0-4	1.5	0-3	4.1
	4-8	1.5	3-6	4.1
	8-12	0.8	6-9	3.7
No-till	0-4	1.9	0-3	4.8
	4-8	1.7	3-6	4.2
	8-12	0.9	6-9	3.8

[a] Indiana. After growing continuous corn for 7 years.

In experiments at the University of Illinois corn and soybeans have been grown with and without wheel traffic compaction on tilled soil (Table 12.04). Heavy wheel traffic on the entire soil surface significantly decreased corn yields when rainfall was adequate or excessive. In years with excessive rainfall, ponding of water occurred on soils with the entire surface compacted, and corn yields were reduced significantly. On other plots, no wheel traffic was applied, or wheel traffic was applied to only the row or between rows before planting — which may be more typical of field conditions. On these plots, yields were not significantly affected compared to no-extra-compaction plots.

Soil densities (g/cc) greater than 1.6 on sands, 1.4 on silt loams, and 1.2 on clay loams have been shown to restrict root growth when soil moisture is less than optimum. Without deep tillage, like moldboard plow, chisel plow, or subsoil, soil density sometimes reaches this critical level. However, with time, changes occur in many soils, especially with no-till and ridge-till systems which improve plant rooting in a dense soil. Increased organic matter near the soil surface improves aggregation and air movement in the soil. Old root channels and earthworm burrows are not disturbed and provide space for new roots. Therefore, a soil density level, which limits rooting within an intensively tilled soil, may not have the same effect with no-till, ridge-till, and shallow-tillage systems.

Stand establishment

Uniform planting depth, good contact between the seed and moist soil, and enough loose soil to cover the seed are necessary to consistently produce uniform stands. Planting shallower than normal in the cool, moist soil common to many conservation tillage seedbeds may partially offset the disadvantage of lower temperatures. However, if dry, windy weather follows planting, germination may be poor and shallow-planted seedlings may be stressed for moisture. Therefore, a normal planting depth is suggested for all tillage systems.

For most conservation-tillage systems, planters and drills are equipped with coulters in front of each seed furrow opener or other devices to cut the surface residues and penetrate the soil. Row cleaners can also be mounted in front of each seed opener. Generally,

Table 12.04. Effects of Wheel Traffic Compaction on Soybean and Corn Yields at Urbana

Compaction treatment	Soybean yield 1986-91	Soybean yield 1992-93	Corn yield 1986-91	Corn yield 1992-93
	Bu/a			
No compaction	38	47	150	197
Half of surface compacted	37	48	146	200
Entire surface compacted	37	44	145	156[a]

[a] Compaction caused water ponding.

coulters should be operated at seeding depth. Row cleaners should be set to move the residue from the row area and as little soil as possible. Extra weight is often needed on planters and drills for no-till so that the soil-engaging components function properly and so that sufficient weight on the drive wheels is ensured. Also, heavy-duty, down-pressure springs on each planter unit may be necessary to penetrate firm, undisturbed soil.

Fertilizer placement

See the section, "Fertilizer management related to tillage systems," Chapter 11.

Weed control

Weed control is essential for profitable production with any tillage system. With less tillage, weed control becomes more dependent on herbicides. However, effective herbicides are available for controlling most all weeds in conservation tillage systems. Herbicide selection and application rate, accuracy, and timing become more important. Application accuracy is especially important with drilled soybeans because row cultivation is impractical. (For specific herbicide recommendations, see Chapter 15.)

Perennial weeds such as milkweed and hemp dogbane may be a problem with conservation tillage systems. Excellent postemergence controls are now available for weeds such as Johnsongrass, shattercane, and yellow nutsedge that formerly required incorporated treatments. Volunteer corn is often a potential problem with tillage systems that leave corn lost at harvest on the soil surface or at a shallow depth. However, excellent herbicides are now available for control of volunteer corn in soybeans. Unless control programs are monitored closely, surface-germinating weeds, such as fall panicum and crabgrass, may also increase with reduced-tillage systems. Some weeds such as velvetleaf are often less of a problem with no-till.

Surface-applied and incorporated herbicides may not give optimum performance under tillage systems that leave large amounts of crop residue and clods on the soil surface. These problems interfere with herbicide distribution and thorough herbicide incorporation.

Herbicide incorporation is impossible in no-till systems. Residual or postemergence herbicides are effective, and mechanical cultivation is usually not done.

Heavy-duty cultivators are available to cultivate with high amounts of surface residues and hard soil. High amounts of crop residues interfere with some rotary hoes and cultivators with multiple sweeps per row. Cultivators equipped with a single coulter and sweep plus two weeding disks per row are effective across a wide range of soil and crop residue conditions.

With the ridge-tillage system, special cultivation

equipment is necessary to form a sufficiently high ridge and to operate through the inter-row residue. Weed control is also accomplished as ridges are rebuilt.

No-till weed control

In conventional and most conservation-tillage systems, existing weeds are destroyed by tillage before planting. No-till systems may require a knockdown herbicide like paraquat or Roundup to control existing vegetation. However, some herbicides such as Extrazine may provide both "burndown" and residual control. The vegetation may be a grass or legume sod or early germinating annual and perennial weeds. Alfalfa and certain perennial broadleaf weeds are not well controlled by paraquat or Roundup. For corn it may be necessary to treat these weeds with Banvel or 2,4-D. A combination of 2,4-D and Banvel is often best to broaden the spectrum of control. Horseweed and prickly lettuce are often associated with no-till. A combination of Roundup plus 2,4-D is often appropriate as a burndown for such weeds.

Insect management

Although insect problems and insect management practices may be affected by reduced tillage, concern about insect problems should not prevent a farmer from adopting conservation-tillage practices. With few exceptions, effective insect-management guidelines and tactics are available, regardless of the tillage system used. Extension entomologists throughout the north central region of Illinois seldom alter insect-management recommendations for different tillage systems.

Insect development rates are closely related to temperature. Insects that spend a portion of their life cycle in the soil may develop more slowly in conservation-tillage systems. For instance, initial emergence of corn rootworm adults is delayed in no-till corn fields. The type of tillage system may also influence insect survival during the winter. Research has shown that survival of corn rootworm eggs during the winter is greater in no-till systems than in more conventional systems, especially if snow cover is deficient and if temperatures remain very cold for an extended period of time.

Conservation-tillage systems may affect other components that influence insect populations. Examples include changes in weed densities and changes in populations of beneficial insects. Poor weed management in some tillage systems is responsible for increasing the densities of cutworms, for example. On the other hand, some weeds attract predators and parasitoids which may suppress some insect pest populations.

The effects of tillage on insects are most prominent in corn. The insects most directly affected are those that overwinter in the soil and become active during the early stages of crop growth. Increases in grassy weed populations, reduced disturbance of soil, and delayed germination caused by cooler soil temperatures may favor buildup of white grubs and wireworms. Seedcorn maggot flies prefer to lay eggs where crop residue has been partially incorporated into the soil. No-till corn stubble may be less attractive to egg-laying flies, but cooler, wetter soils shaded by crop residues may slow germination and increase the period of vulnerability to seed corn maggot injury. On the other hand, corn rootworms are little affected by conservation tillage. (See Table 12.05).

Although soil-dwelling insects are usually affected more than the foliage-feeding insects, some species respond to certain weeds. Black cutworm moths prefer to lay eggs in weedy fields and in fields with unincorporated crop residues. Ryegrass and other grass cover crops, hay crops, and grassy weeds are especially attractive to egg-laying armyworm moths. In no-till fields, serious damage by stalk borers is most likely where grasses were present to attract egg-laying moths the previous August and September.

Conservation tillage favors greater survival of European corn borers in crop residue, but effects in specific fields are minor because moths disperse from emergence sites to lay eggs in suitable fields throughout the local area. Where reduced tillage leads to later planting or slower growth, corn may be less susceptible to attack by first-generation corn borers and more susceptible to second-generation damage.

Although the potential for insect problems is slightly greater with conservation tillage than it is in plowed fields, adequate management guidelines are generally available. (See Chapter 17.)

Disease control

The potential for plant disease is greater when mulch is present than when fields are clear of residue. With clean tillage, residue from the previous crop is buried or otherwise removed. Because buried residue is subject to rapid decomposition, overwintering of pathogens is lessened or reduced with clean tillage systems.

Table 12.05. Potential Effects of Conservation-Tillage Systems on Pests in Corn

Insect	Potential effect*
Armyworm	0 to +++
Black cutworm	+ to +++
Corn earworm	0 to +
Corn leaf aphid	0
Corn rootworm	0
European corn borer	0 to +
Hop vine borer	0 to +++
Seedcorn maggot	+
Slugs	+++
Stalk borer	0 to +++
Stink bugs	+
White grubs	+
Wireworms	+

* Potential effects depend on cropping sequence, weather conditions, and presence or absence of weeds. +++ = substantial increase in pest population; + = some increase; 0 = no effect.

If volunteer corn in continuous corn is a hybrid that is susceptible to disease, early infection with diseases such as southern corn leaf blight or grey leaf spot, for instance, will increase.

Although the potential for plant disease is greater with conservation tillage systems than with clean tillage, disease-resistant hybrids and varieties can help reduce this problem. The erosion-control benefit of conservation tillage must be balanced against the increased potential for disease. Crop rotation or modification of the tillage practice may be justified if a disease cannot otherwise be controlled.

Crop yields

Tillage research is conducted at the seven University of Illinois Agricultural Research and Demonstration Centers (see figure on inside front cover) to evaluate crop yield response to different tillage systems under a wide variety of soil and climatic conditions. Crop yields vary, more due to weather conditions during the growing season than the tillage system used. Corn and soybean yields are generally higher when the crops are rotated compared to either crop grown continuously. It is important with any tillage system that plant stands be adequate, weeds be controlled, soil compaction not be excessive, and adequate nutrients be available.

Comparative yields due to tillage system vary with soil type (Table 12.06). In general, corn and soybean yields have been found to decrease slightly as tillage is reduced on poorly drained and somewhat poorly drained dark soils. An exception is the ridge-till system, which frequently produces higher corn yields on these soils. Flanagan silt loam and Drummer silty clay loam are two examples of poorly drained to somewhat poorly drained soils.

On well- to moderately well-drained, medium-textured, dark- and light-colored soils, expected yields with all tillage systems are quite similar for rotation corn and soybeans. With continuous corn, yields generally decrease as tillage is reduced. Tama silt loam, which is dark, and Downs-Fayette silt loam, which is light-colored, are both well- to moderately well-drained and medium-textured soils.

On somewhat excessively drained sandy soils, conservation-tillage systems that retain surface residues reduce wind erosion and conserve moisture, typically producing high yields.

Soils such as Cisne silt loams, which are very slowly permeable and poorly drained, have a clay pan that restricts root development and water used by the crop with all tillage systems. On such soils, yields are frequently higher with less tillage.

Production costs

To evaluate the profitability of various tillage-planting systems, the affected costs are an important consideration. Various tillage systems may affect the cost of machinery, labor, fertilizers, pesticides, and seed. Grain-handling and drying costs are affected if yields are different. Land cost is normally assumed not to vary with tillage system.

Machinery and labor costs

Machinery-related costs for Illinois farms typically overshadow all other cost categories, except land. Machinery-related costs include the costs for owning and operating machinery and the cost for labor to operate machinery. Many factors and assumptions must be made to estimate the machinery and labor costs for a farm and for various tillage systems.

The machinery-related costs were estimated using a computerized farm machinery selection program. The program determines the optimum set of machinery for a farm. The optimum set of machinery is briefly defined as the set resulting in the minimum total cost for machinery and labor which will complete all field operations in a timely manner with assumed workday probabilities. The program assumes new machinery is purchased and used for up to 10 years. Machinery costs includes costs for depreciation, interest, insurance, housing, repairs, fuel, and lubrication. The program was used to determine the optimum machinery set for various tillage systems and farm sizes. For each machinery set, estimated machinery and labor costs were calculated. The field operations for the tillage systems are summarized in Table 12.07.

Total costs for machinery and labor per acre decrease as the amount of tillage is reduced and as farm size increases (Table 12.08). For reduced tillage, fewer implements and field operations are used, and the necessary power units are often smaller for a given farm size. If a reduced tillage system is used on only part of the land farmed, implements and tractors will need to be available for other portions, so savings may be smaller than shown in Table 12.08.

With reduced tillage systems, labor costs are less because some fall or spring tillage operations are less intensive or eliminated. The labor saved in this way has value only if it reduces the cost of hired labor or if the saved labor time is directed into other productive activities, such as raising livestock, off-farm employment, or farming more land.

Using a drill or narrow-row planter for soybeans is an option for most tillage systems. However, owning a drill for soybeans and a planter for corn often increases the machinery inventory and costs for a corn-soybean farm. The effects on machinery cost for the farm depend on farm size and the cost of the drill. Some no-till drills are quite expensive. For systems that include row cultivation of planted soybeans, the cost increase of the drill may be offset by less use of the planter, row cultivator, and tractor. In comparing no-till planted soybeans (no row cultivation) with no-till drilled soybeans, the no-till drill increased estimated

Table 12.06. Corn and Soybean Yields with Moldboard Plow, Chisel Plow, Disk, and No-Till Systems

Tillage system	Thorp silt loam/ 1987-93	Flanagan silt loam and Drummer clay loam/ 1980-87		Flanagan silt loam and Drummer clay loam/ 1986-93	Cisne silt loam/ 1982-93	Downs-Fayette silt loam/ 1980-93	Tama silt loam/ 1986-93	Tama silt loam/ 1989-93
	Five-year average corn yields, bushels per acre							
Moldboard plow	. . .	. . .	141[c]	165[d]	. . .	168[f]	150[g]	141[h]
Chisel plow	155[a]	155[b]	. . .	158	134[e]	166	149	140
Disk	153	155	134	163	136	166	. . .	141
No-till	148	149	132	156	136	160	143	142
	Five-year average soybean yields, bushels per acre							
Moldboard plow	. . .	46		49	. . .	43	50	. . .
Chisel plow	44	. . .		46	30	48	50	. . .
Disk	46	44		46	29	45	. . .	. . .
No-till	44	43		46	34	41	47	. . .

[a] Urbana, corn-soybean rotation.
[b] Champaign, corn-soybean rotation.
[c] Champaign, continuous corn.
[d] DeKalb, corn-soybean rotation.
[e] Brownstown, corn-soybean rotation.
[f] Perry, corn-soybean rotation.
[g] Monmouth, corn-soybean rotation.
[h] Monmouth, continuous corn.

optimum machinery and labor costs from $38.60 to $45.60 per acre for a 1,000-acre corn-soybean farm.

An extra cost for additional or more expensive pesticides may be associated with some conservation tillage systems. For example, a "burndown" herbicide may be needed with no-till and ridge-tillage systems. These increases are usually more than offset by reduced machinery and labor costs with conservation tillage. Ridge-till can be cost-effective, especially if a "burndown" herbicide is not required and if only a band application of herbicide is used.

Cost for corn and soybean seeds are usually the same for all tillage systems. However, when soybeans are drilled or planted in narrow rows, the seeding rate is usually increased 10 to 20 percent compared to planting in 30-inch or wider rows.

Usually the amount of fertilizers and lime are not varied with different tillage systems. However, the forms and application techniques may vary depending on tillage system. Any differences in cost should be considered. A starter fertilizer for corn is often recommended with conservation tillage, especially with the no-till system. Planter attachments to apply starter fertilizer in a separate band is an expense that should be considered.

Table 12.07. Tillage Operations for Various Systems

After soybeans / After corn	Chisel / moldboard plow		Field cultivate / Chisel		Field cultivate / Disk		No-till / No-till	
	--S = Soybeans, C = Corn --------------------							
Fall								
Harvest	S	C	S	C	S	C	S	C
Mb plow		*						
Chisel plow	*			*				
Apply NH3[a]	*		*		*		*	
Spring								
Disk		*		*		*		
Field cult.	*	*	*	*	*	*		*
Plant	C	S	C	S	C	S	C	S
Row cult.	*	*	*	*	*	*		

[a] Portions of anhydrous ammonia were applied in fall, spring, or as sidedress.

Table 12.08. Estimated Machinery-Related Costs for Various Corn-Soybean Farm Sizes and Tillage Systems[a]

A. Corn and soybeans planted

Farm size and tillage system[b]	Tractors	Combines	Costs		
			Machinery	Labor[c]	Total
	No.-Hp	No.-Hp	$/acre		
500 acres					
Mb plow/chisel	1-120	1-140	68.00	12.80	80.80
Chisel/disk	1-120	1-140	63.60	11.10	74.70
Disk/field cult.	2-80	1-140	59.50	12.20	71.70
No-till/no-till	1-80	1-140	44.40	7.50	51.90
750 acres					
Mb plow	1-100, 1-80	1-140	53.80	14.20	68.00
Chisel	1-100, 1-80	1-140	49.90	12.10	62.00
Disk/field cult.	2-80	1-140	45.30	12.20	57.50
No-till/no-till	1-80	1-140	34.00	7.50	41.50
1000 acres					
Mb plow/chisel	1-160, 1-80	1-215	52.00	9.40	61.40
Chisel/disk	1-160, 1-80	1-215	48.60	8.10	56.70
Disk/field cult.	1-160, 1-80	1-215	47.20	7.90	55.10
No-till/no-till	1.100	1-180	32.90	5.70	38.60
1500 acres					
Mb plow/chisel	1-200, 1-120	1-260	49.40	6.90	56.30
Chisel/disk	1-200, 1-120	1-260	44.40	6.30	50.50
Disk/field cult.	1-200, 1-120	1-260	44.60	5.60	50.20
No-till/no-till	1-120	1-260	29.20	3.90	33.10
2000 acres					
Mb plow/chisel	2-180, 1-120	1-260	47.50	7.20	54.70
Chisel/disk	1-240, 1-120	1-260	40.10	5.60	45.70
Disk/field cult.	1-240, 1-120	1-260	40.00	5.40	45.40
No-till/no-till	1-120	1-260	26.50	3.50	30.00

B. Corn planted and soybeans drilled

Farm size and tillage system[b]	Tractors	Combines	Costs		
			Machinery	Labor[c]	Total
	No.-Hp	No.-Hp	$/acre		
500 acres					
Mb plow/chisel	1-100, 1-80	1-140	69.40	15.20	84.60
Chisel/disk	1-100, 1-80	1-140	65.30	13.10	78.40
Disk/field cult.	2-80	1-140	58.40	13.20	71.60
No-till/no-till	1-80	1-140	49.50	8.40	57.90
750 acres					
Mb plow/chisel	1-120, 1-80	1-140	57.40	12.70	70.10
Chisel/disk	1-120, 1-80	1-140	53.60	11.00	64.60
Disk/field cult.	1-120, 1-80	1-140	52.00	10.70	62.70
No-till/no-till	1-140	1-140	43.00	7.60	50.60
1000 acres					
Mb plow/chisel	1-160, 1-100	1-215	55.60	8.70	64.30
Chisel/disk	1-140, 1-100	1-215	57.40	7.80	59.20
Disk/field cult.	1-140, 1-100	1-215	50.10	7.50	57.60
No-till/no-till	1-160	1-180	40.00	5.60	45.60
1500 acres					
Mb plow/chisel	1-240, 1-160	1-260	51.00	6.40	57.40
Chisel/disk	1-180, 1-140	1-260	44.60	6.00	50.60
Disk/field cult.	1-160, 1-140	1-260	43.60	5.90	49.50
No-till/no-till	1-160, 1-100	1-260	36.70	3.90	40.60
2000 acres					
Mb plow/chisel	2-180, 1-160	1-260	49.40	6.80	56.20
Chisel/disk	2-180, 1-160	1-260	44.80	5.70	50.50
Disk/field cult.	2-180, 1-160	1-260	44.70	5.30	50.00
No-till/no-till	1-160, 1-120	1-260	34.20	3.70	37.90

[a] Optimum size and number of tractors with matched implements and combines with attached headers were determined and costs estimated using Farm Machinery Selection Program (Siemens, Hamburg, and Twirl, 1990). These sizes and numbers should be regarded as the minimum to perform the operations in a timely manner. Costs for applying P and K fertilizers, herbicides, and lime are not included.
[b] Corn-soybean rotation assumed. Operations for each tillage system are given in Table 12.07.
[c] Labor assumed to cost $10 per hour.

Chapter 13.
No Tillage

No-till is a system wherein the soil is left undisturbed. The only soil disturbance is of a narrow band by soil engaging components of the planter or drill. In addition to double-disk seed furrow openers and press wheels or firming wheels, soil-engaging components often include row cleaners, coulters, or other devices attached to the planter or drill.

No-till is very effective in reducing the potential for soil erosion due to wind and water. With no-till, the maximum amount of plant residue remains on the soil surface compared to other tillage systems. Surface residue protects the soil from raindrop impact and, thus, reduces splash erosion. In addition, surface residue slows the speed of water flowing down a slope, allowing more time for the water to infiltrate into the soil.

The trend toward the adoption of no-till management systems for crop production in Illinois was accelerated by the 1985 Food Security Act. Provisions of the Act require farmers to develop and apply an approved conservation plan on highly erodible fields. Many of the plans include the use of a no-till system. In addition, many farmers are adopting a no-till system because they find it to be cost-effective.

No-till planters

No-till planters are specifically designed to plant in undisturbed soil which has a high percentage of the surface covered with residue. In addition to field conditions, planter performance is influenced by planter features, attachments, adjustment, and operation. Successful planting in residue-covered and undisturbed fields depends on planter weight and appropriate down-pressure springs to transfer the weight to the planting units and other soil-engaging components in order to cut the residue and achieve adequate soil penetration.

Row-cleaning devices

In heavy surface residue, use of row cleaners to move residue away from the row aids in soil warming and may improve seed placement and stand establishment. Early soil warming contributes to faster early growth, especially in poorly drained soils. Row cleaners may also be beneficial in reducing the toxic effects of allelopathy. The potential for allelopathy occurs when the toxins and bacteria from decaying residue affect growth of new plants. The toxic effect is most likely to occur when crops are not rotated — for example, when corn follows corn.

Among the devices used for row cleaning are double-disk furrowers, row-cleaning brushes, sweeps or horizontally mounted disks, and spoked wheels. The most popular of these are the spoked wheels.

Coulters

A coulter is usually mounted in front of each row unit of a no-till planter. The coulter is primarily for cutting through the residue and loosening the soil in the row to planting depth. It has little effect on soil warming or allelopathy. Coulter operating depth in relation to seeding depth is more consistent when the coulter is mounted on the planter unit rather than on a toolbar.

Several types of coulters are available for no-till planters (Figure 13.01). The most commonly used is the ¾-inch-wide or 1-inch-wide fluted coulter. Generally, wider coulters increase tillage action and require more weight for penetration; a total weight of 400 to 600 pounds per coulter may be required. Wider coulters also may throw excessive amounts of soil from the row, especially when operated at higher planting speeds.

Compared to fluted coulters, rippled or smooth coulters perform less tillage, require less weight for penetration, allow higher planting speeds, and are preferred for cutting residue.

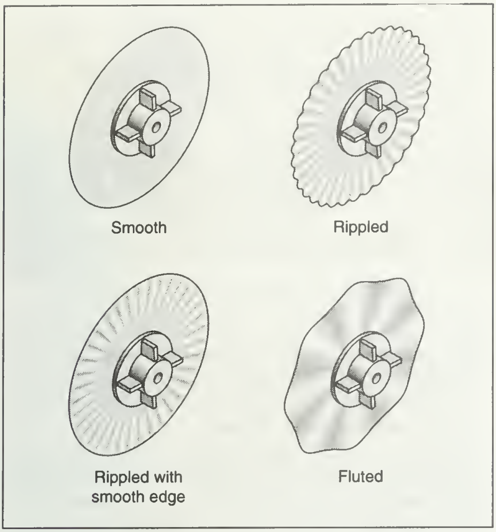


Figure 13.01. Common coulter styles.

Seed furrow openers

Seed furrow openers create a well-defined slit in the soil where seed is placed at the desired depth. Planters are commonly equipped with either the double-disk or staggered double-disk seed furrow openers.

The staggered double-disk opener is a modification of the double-disk version. The leading edge of one disk, slightly in front of the other, provides a definite cutting edge. The trailing disk helps open the seed furrow. Planters with staggered double-disk seed furrow openers may not require as much weight to achieve soil penetration, especially if operated without a leading coulter. The double-disk opener will satisfactorily cut well-distributed soybean residue and penetrate a soft soil without a leading coulter. Research indicates no difference in seed spacing uniformity due to the type of opener.

Seed covering

Good seed-to-soil contact is essential for seed germination and seedling emergence. Some planters use a narrow press wheel to improve seed-soil contact. This wheel operates just behind the seed furrow opener and presses the seed into the bottom of the furrow. Commonly used seed covering devices include a small disk blade on each side of the row, a press wheel, an angled wheel on each side of the row, or a combination of these. Currently, there is no combination of covering devices and press wheels that have proven to offer a distinct advantage across all variations in soil conditions.

Weight and down-pressure springs

Additional weight is usually required on no-till planters to achieve uniform soil penetration. Down-pressure springs which transfer weight from the toolbar to the row units, are usually located on the parallel linkage supporting the row units and may need tightening to achieve adequate penetration of the soil-engaging components. When no-till planting in hard soil conditions, heavy duty down-pressure springs may be required in addition to extra weight.

Down pressure must be sufficient to hold the planting unit gauge wheels in firm contact with the soil so that a uniform planting depth is maintained. However, the planter must be heavy enough to prevent the springs from lifting too much weight from the seed-metering drive wheels, causing excessive wheel slippage and lower seeding rate.

The operator's manual serves as a guide for setting the planter. Final adjustments, such as planting depth and seeding rate, should be made in the field. Also, soil penetration and residue cutting should be checked in the field and appropriate adjustments made to ensure proper seed placement and to enhance seed-to-soil contact.

No-till drills

Erosion control is improved when soybeans are drilled in row spacings of 10 inches or less, which also provides a nearly equidistant plant spacing, resulting in greater yield potential. Narrow rows form a full canopy sooner, shading the soil earlier which reduces weed pressure. No-till drilling a crop leaves the field relatively smooth for easier harvesting and for no-tilling the following crop. It is difficult to obtain consistent depth of planting and uniform stand establishment in a field that has a rough surface which may have been caused by previous wheel traffic, small ridges created by tillage, a planter, a row cultivator, or erosion.

Soil-engaging components of no-till drills are much like those on no-till planters and must be able to cut and handle large amounts of residue, penetrate the soil, and establish good seed-to-soil contact.

There are two basic types of no-till drills: converted drills (conventional drills, equipped with double-disk seed furrow openers, to which a gang of coulters has been added), and drills designed specifically for no-till. For many situations, either type may provide satisfactory performance. However, in fields with heavy residue and hard surface soils — and in large-scale operations — a drill designed specifically for no-till will probably perform better.

Converted drills (Figure 13.02) are usually a three-point mounted conventional drill on a wheeled carrier, equipped with a coulter positioned in front of each double-disk seed furrow opener. Ripple and fluted coulters are commonly used (Figure 13.01). Weight may need to be added to the carrier for sufficient

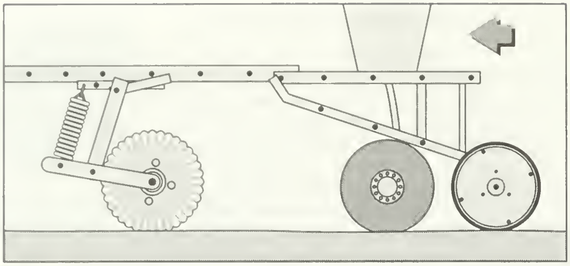


Figure 13.02. Drill mounted on a coulter cart.

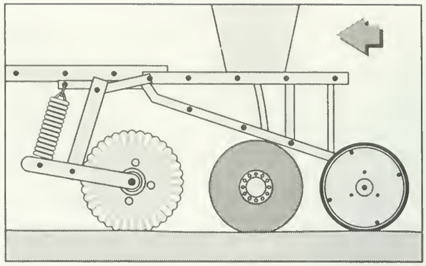


Figure 13.03. No-till drill with coulters.

penetration of the coulters. It is important for the seed openers to track in the coulter slots.

Drills designed specifically for no-till (Figure 13.03) have all soil-engaging components on a single unit. In hard soil conditions, additional weight may be needed to help ensure penetration of these components. On some no-till drills, the openers are staggered to allow improved residue flow.

Individual openers should have sufficient down-pressure and independent depth control with enough vertical movement to allow all rows to operate at the desired depth. Depth control is more consistent if fields are smooth.

Some no-till drills are not equipped with coulters but use the seed furrow openers to cut the residue and penetrate the soil to seeding depth. These drills often use staggered double-disk seed furrow openers without a coulter in front. On these drills, the leading disk, usually about 1/2 to 1 inch in front of the other, cuts the residue and the following disk aids in opening the seed furrow. At least one brand of drill uses a large diameter single disk set at a slight angle, to cut through the residue and serve as a seed furrow opener. This design provides for minimal soil disturbance and requires less weight for penetration.

Spacing, weight, and down pressure

A wider row spacing (10 or 12 inches rather than 7 or 8 inches) on a no-till drill provides more clearance for residue flow and requires less weight per unit of drill width for soil penetration.

Depending on coulter type and width, opener design, and field conditions, up to 600 pounds per row may be needed on a drill to provide for adequate penetration. Down-pressure springs on individual rows must transfer enough weight from the drill frame for all soil-engaging components to function as intended. Coulters and seed furrow openers should operate at the desired seed-depth setting. Depth control devices and seed-press wheels must be in firm contact with the soil. As the springs are tightened, especially in hard soil conditions, the springs may physically lift the drive mechanism of the drill off the ground, causing a reduced seeding rate due to wheel slippage. In such conditions, extra weight on the drill frame may solve the problem.

Press wheels and depth control

With a converted drill, depth of seed placement may be controlled by the depth of the coulter gang or by the press wheels behind each seed opener. When seeding depth is controlled by the coulters, seed-to-soil contact is obtained with a narrow press wheel running directly over the seed. Using this method, extra weight or heavy down-pressure springs are not needed for the seed furrow openers, but extra weight or load may be needed on the coulter carrier. A harrow behind the drill is often used to improve seed coverage.

Several no-till drills use coulters to cut residue and both the coulters and seed furrow openers to loosen a strip of soil. A wider press wheel mounted adjacent to the seed furrow opener controls depth. Total weight and down-pressure springs must be sufficient to force the coulters and openers into the soil to the desired planting depth and keep adequate pressure on the press wheels. The press wheels must be wide enough to ride on firm soil adjacent to the seed furrow in order to gauge seeding depth and help to cover the seed.

Another option for no-till drills is the use of a pair of angled press wheels behind each opener to control planting depth. Clearance between adjacent rows may prevent the use of angled press wheels in large amounts of residue.

General operation

No-till drills must be heavier than conventional drills. Enough weight and sufficient down-pressure springs are needed to cause the soil-engaging components to function properly. Weight is essential for cutting residue and penetrating soil. Adequate weight also keeps the depth control wheels, seed press wheels, and the drive mechanism in firm contact with the soil.

More tractor power is required to lift and pull the greater weight of a no-till drill, especially at high operating speeds. High operating speeds may assist residue flow but also may sacrifice some seed depth uniformity.

Residue flow through the drill is better if the residue is not shredded. When residue is standing and attached to the soil, less of it has to be cut by the drill, and the soil holds the residue as the drill passes through it. Leaving concentrations of residue in the field at harvest should be avoided; well-distributed residue provides better erosion control and passes through a drill better. A chaff spreader, especially for combines with wide headers, is important.

Weed control

No-till systems require a well-designed weed control program including proper timing and accurate application of herbicides. Effective programs are available that include the application of herbicides as early preplant, burndown, preemergence, and postemergence.

Early preplant plus preemergence or postemergence

Early weed growth may be successfully controlled by applying an early preplant (EPP) herbicide. An EPP herbicide is usually applied prior to the germination of most weed seed. However, if the EPP herbicide has postemergence activity or foliar activity, it can effectively control small emerged weeds. EPP herbicides, such as Extrazine for corn and Canopy for soybeans, can provide both burndown and residual control. However, with some herbicides it is often preferable to use a treatment including Roundup plus 2,4-D for improved control of existing vegetation.

An EPP herbicide application is unlikely to provide season-long weed control, especially if the application is made relatively early or if the soil is disturbed significantly during the planting application. An additional herbicide treatment may be needed. One option is to use a split application, with one portion applied EPP and the other soon after planting. Another option is to apply an EPP treatment and follow up with a postemergence herbicide program.

The EPP program has several advantages. Herbicide performance is usually excellent when applied in March or early April because cool weather and spring rains are likely, which enhances herbicide performance. Also, the expense of a "burndown herbicide" may be eliminated. The main disadvantage of EPP programs is that for late planted crops, preemergence or postemergence treatments may be needed to maintain season-long control.

Burndown plus preemergence or postemergence

With no-till, weeds established prior to planting and weeds that emerge later must all be controlled. Weeds established before planting can be controlled with "burndown" herbicides such as Roundup or Gramoxone Extra. With early planting, especially of corn, there may be no weeds present, and a burndown herbicide may not be needed. Emerged weeds, if small, may also be controlled by some preemergence herbicides applied at planting. If preemergence herbicides are not used, several excellent postemergence herbicides are available. The type of herbicide selected and the application rate will depend on the type of vegetation present and the crop.

See the section titled "Conservation Tillage and Weed Control" in Chapter 15 and University of Illinois College of Agriculture Circular 1306, "Weed Control Systems for Lo-Till and No-Till," for additional information on weed control using a no-till system.

Fertilizer management

Since with no-till, soils are cooler, wetter, and less well-aerated, the ability of crops to utilize nutrients may be altered and adjustments in fertilizer management may be important.

Stratification of immobile nutrients, such as P and K, with high concentrations near the soil surface and decreasing concentrations with depth, has been routinely observed where no-till and other conservation tillage systems — such as disk and chisel plow — have been used for a period of at least 3 to 4 years. This stratification results from both the additions of fertilizer to the soil surface and the "cycling" of nutrients by plants. Plant roots uptake nutrients from well below the soil surface; some of these nutrients are then deposited on the soil surface in the form of crop residue.

When soil moisture is adequate, nutrient stratification has not been found to cause a decrease in nutrient availability because root activity in the fertile zone near the soil surface is sufficient to supply plant needs. The residue enhances root activity near the soil surface by reducing evaporation of water, which helps keep the surface soil moist and cool. If the surface dries out and the shallow roots become inactive, nutrient uptake could be reduced, especially if the lower portions of the old plow layer are most likely to be the areas of lower fertility.

Details on fertility are covered in Chapter 11, "Soil Testing and Fertility." The key points on fertility management for no-till are:

A. Liming to neutralize soil acidity is important, especially with surface applications of nitrogen (N) fertilizer. Lime rates may need to be adjusted and applications more frequent with no-till. Where possible, lime should be incorporated as needed prior to establishing a no-till system.

B. Any P and K deficiencies should be corrected prior to switching to no-till because surface applications of P and K move deeper into the soil very slowly.

C. After several years of no-till, it may be desirable to take soil samples for nutrient analysis from near the soil surface (0 to 3 inches deep) and from lower portions of the old tillage zone (3 to 7 inches deep). If depletion of the nutrients or accumulation of acidity in the lower portion occurs and crops show

nutrient deficiency, moldboard or chisel plowing can correct the stratification problem.

D. Starter fertilizer appears to be more important with no-till, especially for continuous corn. More information on the use of starter for no-till is provided in Chapter 11.

E. Nitrogen management is very important to success with no-till planting of corn. Anhydrous ammonia applied in the spring before planting can severely injure or kill corn seedlings if corn is planted directly above applied anhydrous ammonia. Anhydrous can safely be applied in the fall, sidedressed after planting, or in the spring before planting, if applied between rows to be planted. There is a potential for loss of a portion of the nitrogen surface applied on no-till in the form of urea or urea-ammonium nitrate solutions if rain is not received within 3 days after application. To minimize this loss potential, apply these products 1 to 2 days ahead of a rain or use a urease inhibitor.

Soil density

Untilled soil usually has a greater density (weight per unit volume) and less airspace than a tilled soil. The density of a tilled soil is lower after primary tillage, but with secondary tillage, wheel traffic, and several wetting and drying periods, it becomes about equal in density to that of an untilled soil by harvest.

Soil densities greater than 1.4 to 1.6 g/cc have been shown to restrict root growth, when rainfall is either more or less than optimum. With no-till, soil density sometimes reaches this critical level. High soil density may also reduce soil drainage, soil aeration, and fertilizer uptake, while increasing the potential for herbicide injury.

However, over time, changes occur in the soil under no-till which may improve the effect of dense soil on plant rooting: organic matter near the soil surface may improve aggregation and air movement in the soil; and old root channels and earthworm burrows remain as undisturbed pathways for new roots. Therefore, high-soil density, which may limit rooting in tilled soil, may not have the same effect in continuous no-till.

Excessive compaction can cause yield decreases when too much or too little soil moisture is available. With too much water, compaction reduces drainage, causes denitrification, and limits the availability of oxygen to the roots. With too little moisture, the root system must seek moisture from the subsoil, and excessive compaction may prevent the roots from getting to that moisture.

Soil organic matter and aggregation

Soil organic matter content tends to stabilize at a certain level with any tillage system and crop rotation. With no-till, partially decayed plant material tends to concentrate near the soil surface because the residue is left on the surface and plant roots tend to be more numerous near the surface.

Continuous no-till leads to better soil aggregation. A high level of soil aggregation indicates good soil structure which improves plant emergence and rooting, aeration, drainage, and water infiltration. Good soil structure also decreases the susceptibility of soil to compaction.

An Indiana study showed that after 5 years of continuous no-till corn, aggregation in the top 2 inches of soil was increased. However, moldboard plowing the plots returned the aggregation index near the soil surface to its original level.

Earthworm and root channels

Physical properties of soil are not determined solely by mechanical manipulations of the soil or by surface residue. Biological populations can significantly improve soil physical conditions important to plant growth and may play a significant role in maintaining good soil tilth in the absence of tillage.

Channels for water movement and rooting are provided by earthworms and roots of previous crops. Tillage tends to reduce earthworm populations by speeding soil drying and freezing rates, disrupting earthworm burrows, and burying the plant residue that the worms use for food. Much more research is needed to explain all of the impact of no-till on soil biology.

Soil drainage

Research and farmer experiences during the past 20 years have shown that no-till may increase crop yields on soils with no drainage problems. Improving drainage on poorly drained soil improves crop performance, especially with no-till.

Equipment alterations to soils

Problems such as compacted layers or "tillage pans," excessive traffic areas, ruts from wheel traffic, and livestock trails are troublesome with no-till. Compacted layers from previous plowing and disking can limit rooting. Natural soil processes such as freezing and thawing, wetting and drying, and the channeling of earthworms and roots eventually loosen or reduce the effects of compacted zones under no-till, but these processes are slow. The use of a chisel plow or subsoiler before beginning no-till should speed the process if compaction is not reintroduced by subsequent traffic and excessive secondary tillage. Benefits from subsoiling can generally be expected only when it disrupts or loosens a drainage- or root-restricting layer. The disruption allows excess water to drain and plant roots to explore a greater volume of soil.

Some soils have a natural hardpan or claypan at a

depth of 12 to 18 inches. Generally, the layers below the pan are also compacted and poorly drained. In such cases, chiseling or subsoiling is ineffective because it is impossible to break through to a better-drained layer.

Soil surface compaction and non-uniformity from wheel or livestock traffic can cause uneven seed placement and poor stands in no-till. To the extent possible, no-till fields should be kept smooth. Where the soil surface is not smooth, shallow tillage may be needed to obtain uniform seed placement.

Crop rotation

In general, crop rotation improves chances for success with no-till. Several long-term studies show that a corn/soybean rotation improves the yield potential of no-till corn compared to continuous corn. With continuous no-till corn, several factors — including lower soil temperature and allelopathy — may cause the lower yield potential. Lower yields have been especially evident on poorly drained soil and high organic-matter soils.

Small grains such as wheat or rye germinate at much lower soil temperature than corn (32°F versus 55°F), but also benefit from crop rotation when residue is left on the soil surface. For small grain, the deleterious effects from monoculture are most likely due to allelopathy and disease buildup.

The use of row cleaners may improve the germination, early growth rate, and potential yield of no-till crops planted without rotation.

Adaptability of no-till to specific locations

Soil, climate, and crop rotation influence the success of no-till. In addition, success is influenced by pest control, fertility practices, and management experience of the farm operator. The decision to adopt no-till may be based on net return, potential for reduction in soil erosion, or eligibility for government programs. Yield potential of crops grown with no-till is an important consideration.

Several states have classified soils into tillage management groups for corn and soybean production. Soil types are placed in groups according to unique soil properties and their influence on crop yield with no-till planting. Soil characteristics include drainage, texture, organic matter, and slope. A summary of the classification as might be applied to Illinois follows:

A. *Equal yield.* In central and northern Illinois, when crops are rotated and when used on naturally well-drained soils — or on slopes greater than 6 percent — no-till should provide yield potential equal to that of other systems for corn, soybeans, and wheat.

B. *Higher yield.* In southern Illinois, with crop rotation, well-drained soils, slopes greater than 6 percent, or very low organic-matter soils, no-till should provide a higher yield potential than other tillage systems.

C. *Higher yield.* In southern Illinois, on light (very low organic-matter), somewhat poorly drained and poorly drained silt loams (that are nearly level to gently sloping, overlying very slowly permeable fragipan-like soil layers that restrict plant rooting and water movement), no-till yield potential should be higher than with other tillage systems.

D. *Lower yield.* Compared to other tillage systems, slightly lower yields are expected with no-till on dark, poorly drained silty clay loams to clay soils with 0 to 2 percent slope.

An established sod or cover crop must be managed to avoid excessive water use and mouse and mole problems prior to no-till planting corn or other grain crop.

Chapter 14.
Water Management

A superior water management program seeks to provide an optimum balance of water and air in the soil that will allow full expression of genetic potential in plants. The differences among poor, average, and record crop yields generally can be attributed to the amount and timing of soil water supply.

Improving water management is an important way to increase crop yields. By eliminating crop-water stress, you will obtain more benefits from improved cultural practices and realize the full yield of the cultivars now available.

To produce maximum yields, the soil must be able to provide water as it is needed by the crop. But the soil seldom has just the right amount of water for maximum crop production; a deficiency or a surplus usually exists. A good water management program seeks to avoid both extremes through a variety of measures. These measures include draining waterlogged soils; making more effective use of the water-holding capacity of soils so that crops will grow during periods of insufficient rainfall; increasing the soil's ability to absorb moisture and conduct it down through the soil profile; reducing water loss from the soil surface; and irrigating soils with low water-holding capacity.

In Illinois, the most frequent water management need is improved drainage. Initial efforts in the nineteenth century to artificially drain Illinois farmland made our soils among the most productive in the world. Excessive water in the soil limits the amount of oxygen available to plants and thus retards growth. This problem occurs where the water table is high or where water ponds on the soil surface. Removing excess water from the root zone is an important first step toward a good water management program. A drainage system should be able to remove water from the soil surface and lower the water table to about 12 inches beneath the soil surface in 24 hours and to 21 inches in 48 hours.

The benefits of drainage

A well-planned drainage system will provide a number of benefits: better soil aeration, more timely field operations, less flooding in low areas, higher soil temperatures, less surface runoff, better soil structure, better incorporation of herbicides, better root development, higher yields, and improved crop quality.

Soil aeration. Good drainage ensures that roots receive enough oxygen to develop properly. When the soil becomes waterlogged, aeration is impeded and the amount of oxygen available is decreased. Oxygen deficiency reduces root respiration and often the total volume of roots developed. It also impedes the transport of water and nutrients through the roots. The roots of most nonaquatic plants are injured by oxygen deficiency; and prolonged deficiency may result in the death of some cells, entire roots, or in extreme cases the whole plant. Proper soil aeration also will prevent rapid losses of nitrogen to the atmosphere through denitrification.

Timeliness. Because a good drainage system increases the number of days available for planting and harvesting, it can enable you to make more timely field operations. Drainage can reduce planting delays and the risk that good crops will be drowned or left standing in fields that are too wet for harvest. Good drainage may also reduce the need for additional equipment that is sometimes necessary to speed up planting when fields stay wet for long periods.

Soil temperature. Drainage can increase soil surface temperatures during the early months of the growing season by 6° to 12°F. Warmer temperatures assist germination and increase plant growth.

Surface runoff. By enabling the soil to absorb and store rainfall more effectively, drainage reduces runoff from the soil surface and thus reduces soil erosion.

Soil structure. Good drainage is essential in main-

taining the structure of the soil. Without adequate drainage the soil remains saturated, precluding the normal wetting and drying cycle and the corresponding shrinking and swelling of the soil. The structure of saturated soil will suffer further damage if tillage or harvesting operations are performed on it.

Herbicide incorporation. Good drainage can help avoid costly delays in applying herbicide, particularly postemergence herbicides. Because some herbicides must be applied during the short time that weeds are still relatively small, an adequate drainage system may be necessary for timely application. Drainage may also help relieve the cool, wet-stress conditions that increase crop injury by some herbicides.

Root development. Good drainage enables plants to send roots deeper into the soil so they can extract moisture and plant nutrients from a larger volume of soil. Plants with deep roots are better able to withstand drought.

Crop yield and quality. All of the benefits previously mentioned contribute to greater yields of higher-quality crops. The exact amount of the yield and quality increases depends on the type of soil, the amount of rainfall, the fertility of the soil, crop management practices, and the level of drainage before and after improvements are made. Of the few studies that have been conducted to determine the benefits of drainage, the most extensive in Illinois was initiated at the Agronomy Research Center at Brownstown. This study evaluated drainage and irrigation treatments with Cisne and Hoyleton silt loams.

Drainage methods

A drainage system may consist of surface drainage, subsurface drainage, or some combination of both. The kind of system you need depends in part upon the ability of the soil to transmit water. The selection of a drainage system ultimately should be based on economics. Surface drainage, for example, would be most appropriate where soils are impermeable and would therefore require too many subsurface drains to be economically feasible. Soils of this type are common in southern Illinois.

Surface drainage

A surface drainage system is most appropriate on flat land with slow infiltration and low permeability and on soils with restrictive layers close to the surface. This type of system removes excess water from the soil surface through improved natural channels, manmade ditches, and shaping of the land surface. A properly planned system eliminates ponding, prevents prolonged saturation, and accelerates the flow of water to an outlet without permitting siltation or soil erosion.

A surface drainage system consists of a farm main, field laterals, and field drains. The farm main is the outlet serving the entire farm. Where soil erosion is a problem, a surface drain or waterway covered with vegetation may serve as the farm main. Field laterals are the principal ditches that drain adjacent fields or areas on the farm. The laterals receive water from field drains, or sometimes from the surface of the field, and carry it to the farm main. Field drains are shallow, graded channels (with relatively flat side slopes) that collect water within a field.

A surface drainage system sometimes includes diversions and interceptor drains. Diversions are channels constructed across the slope of the land to intercept surface runoff and prevent it from overflowing bottomlands. Diversions are usually located at the bases of hills. These channels simplify and reduce the cost of drainage for bottomlands.

Interceptor drains collect subsurface flow before it resurfaces. These channels may also collect and remove surface water. They are used on long slopes that have grades of one percent or more and on shallow, permeable soils overlying relatively impermeable subsoils. The location and depth of these drains are determined from soil borings and the topography of the land.

The principal types of surface drainage configurations are the random and parallel systems (Figure 14.01). The **random system** consists of meandering field drains that connect the low spots in a field and provide an outlet for excess water. This system is adapted to slowly permeable soils with depressions too large to be eliminated by smoothing or shaping the land.

The **parallel system** is suitable for flat, poorly drained soils with many shallow depressions. In a field that is cultivated up and down a slope, parallel ditches can be arranged to break the field into shorter lengths. The excess water thus erodes less soil because it flows over a smaller part of the field before reaching a ditch. The side slopes of the parallel ditches should be flat enough to permit farm equipment to cross them. The spacing of the parallel ditches will vary according to the slope of the land.

For either the random or parallel systems to be fully effective, minor depressions and irregularities in the soil surface must be eliminated through land grading or smoothing.

Bedding is another surface drainage method that is used occasionally. The land is plowed to form a series of low, narrow ridges separated by parallel, dead furrows. The ridges are oriented in the direction of the steepest slope in the field. Bedding is adapted to the same conditions as the parallel system, but it may interfere with farm operations and does not drain the land as completely. It is not generally suited for land that is planted in row crops because the rows adjacent to the dead furrows will not drain satisfactorily. Bedding is acceptable for hay and pasture crops, although

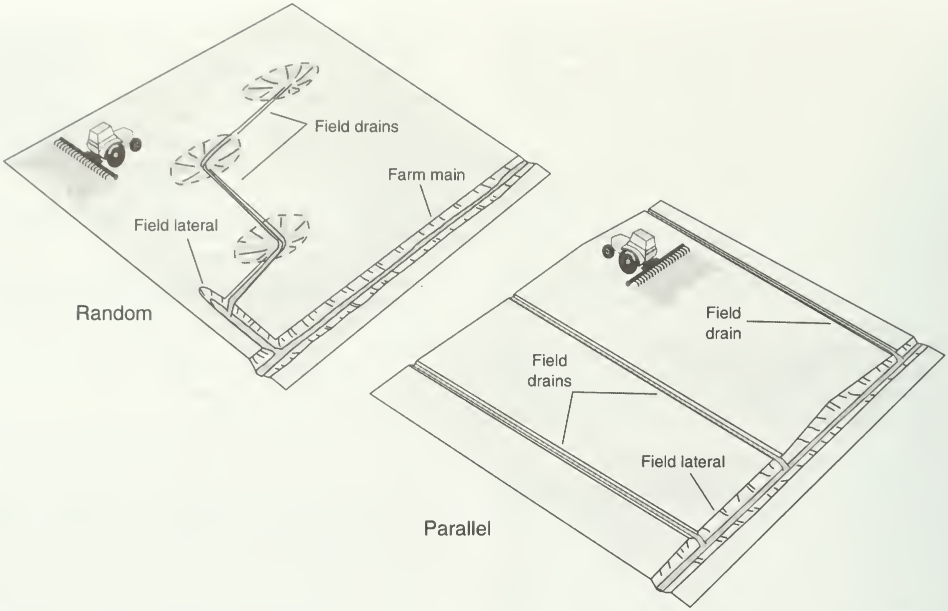


Figure 14.01. Types of surface drainage systems.

it will cause some crop loss in and adjacent to the dead furrows.

Subsurface drainage

Many of the deep, poorly drained soils of central and northern Illinois respond favorably to subsurface drainage. A subsurface drainage system is used in soils permeable enough that the drains do not have to be placed too closely together. If the spacing is too narrow, the system will not be economical. By the same token, the soil must be productive enough to justify the investment. Because a subsurface drainage system functions only as well as the outlet, a suitable one must be available or constructed. The topography of the fields also must be considered because the installation equipment has depth limitations and a minimum amount of soil cover is required over the drains.

Subsurface systems are made up of an outlet or main, sometimes a submain, and field laterals. The drains are placed underground, although the outlet is often a surface drainage ditch. Subsurface drainage conduits are constructed of clay, concrete, or plastic.

There are four types of subsurface systems: the random, the herringbone, the parallel, and the double-main (Figure 14.02). A single system or some combination of systems may be chosen according to the topography of the land.

For rolling land, a **random system** is recommended. With this system, the main drain is usually placed in a depression. If the wet areas are large, the submains and lateral drains for each area may be placed in a gridiron or herringbone pattern to achieve the required drainage.

With the **herringbone system**, the main or submain is often placed in a narrow depression or on the major slope of the land. The lateral drains are angled upstream on either side of the main. This system sometimes is combined with others to drain small or irregular areas. Because two laterals intersect the main at the same point, however, more drainage than necessary may occur at that intersection point. The herringbone system may also cost more because it requires more junctions. Nevertheless, it can provide the extra drainage needed for the heavier soils that are found in narrow depressions.

The **parallel system** is similar to the herringbone system, except that the laterals enter the main from only one side. This system is used on flat, regularly shaped fields and on uniform soil. Variations are often used with other patterns.

The **double-main system** is a modification of the parallel and herringbone systems. It is used where a depression, frequently a natural watercourse, divides the field in which drains are to be installed. Sometimes the depression may be wet due to seepage from higher ground. A main placed on either side of the depression intercepts the seepage water and provides an outlet for the laterals. If only one main were placed in the center of a deep and unusually wide depression, the

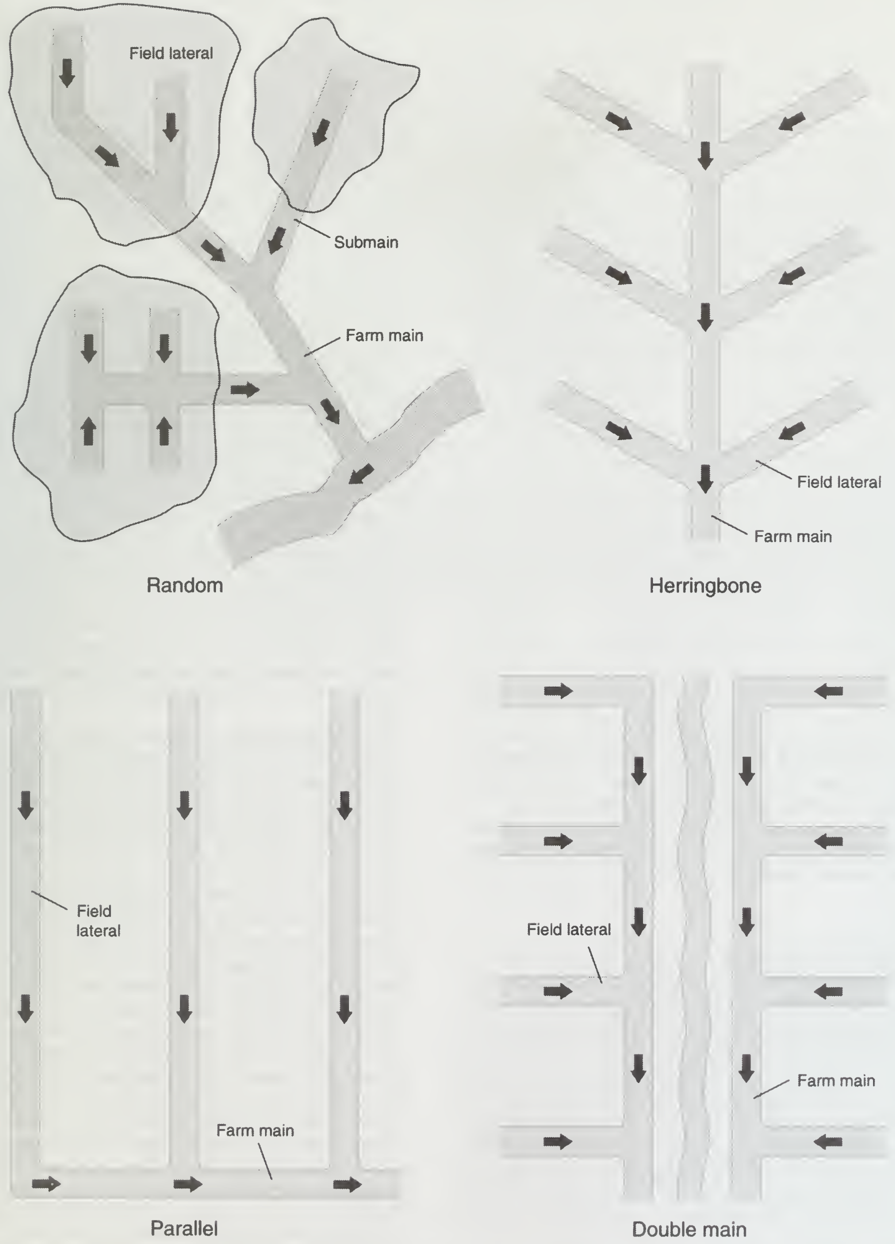


Figure 14.02. Types of subsurface drainage systems. The arrows indicate the direction of water flow.

grade of each lateral would have to be changed at some point before it reaches the main. A double-main system avoids this situation and keeps the gradelines of the laterals uniform.

The advantage of a subsurface drainage system is that it usually drains soil to a greater depth than surface drainage. Subsurface drains placed 36 to 48 inches deep and 80 to 100 feet apart are suitable for crop production on many medium-textured soils in Illinois. When properly installed, these drains require little maintenance, and because they are underground, do not obstruct field operations.

For more specific information about surface and subsurface drainage systems, obtain the Extension Circular 1226, *Illinois Drainage Guide*, from your county Extension adviser. This publication discusses the planning, design, installation, and maintenance of drainage systems for a wide variety of soil, topographic, and climatic conditions.

The benefits of irrigation

During an average year, most regions of Illinois receive ample rainfall for growing crops; but, as shown in Figure 14.03, rain does not occur when the crops need it the most. From May to early September, growing crops demand more water than is provided by precipitation. For adequate plant growth to continue during this period, the required amount of water must be supplied by stored soil water or by irrigation. During the growing season, crops on deep, fine-textured soils may draw upon moisture stored in the soil, if the normal amount of rainfall is received throughout the year. But if rainfall is seriously deficient or if the soil has little capacity for holding water, crop yield may be reduced. Yield reductions are likely to be most severe on sandy soils or soils with claypans. Claypan soils restrict root growth, and both types of soils often cannot provide adequate water during the growing season.

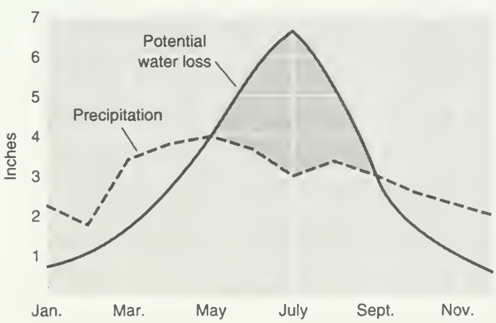


Figure 14.03. Average monthly precipitation and potential moisture loss from a growing crop in central Illinois.

To prevent crop-water stress during the growing season, more and more producers are using irrigation. It may be appropriate where water stress can substantially reduce crop yields and where a supply of usable water is available at reasonable cost. Irrigation is still most widely used in the arid and semi-arid parts of the United States, but it can be beneficial in more humid states such as Illinois. Almost every year, Illinois corn and soybean yields are limited by drought to some degree, even though the total annual precipitation exceeds the water lost through evaporation and transpiration (ET).

With current cultural practices, a good crop of corn or soybeans in Illinois needs at least 20 inches of water. All sections of the state average at least 15 inches of rain from May through August. Thus satisfactory yields require at least 5 inches of stored subsoil water in a normal year.

Crops growing on deep soil with high water-holding capacity, that is, fine-textured soil with high organic-matter content, may do quite well if precipitation is not appreciably below normal and if the soil is filled with water at the beginning of the season.

Sandy soils and soils with subsoil layers that restrict water movement and root growth cannot store as much as 5 inches of available water. Crops planted on these soils suffer from inadequate water every year. Most of the other soils in the state can hold more than 5 inches of available water in the crop-rooting zone. Crops on these soils may suffer from water deficiency when subsoil water is not fully recharged by about May 1 or when summer precipitation is appreciably below normal or poorly distributed throughout the season.

The probability of getting at least one inch of rain in any week is shown in Figure 14.04. One inch of rain per week will not replace ET losses during the summer, but it can keep crop-water stress from severely limiting final grain yields on soils that can hold water reasonably well. This probability is lowest in all sections of Illinois during July, when corn normally is pollinating and soybeans are flowering.

Water stress delays the emergence of corn silks and shortens the period of pollen shedding, thus reducing the time of overlap between the two processes. The result is incomplete kernel formation, which can have disastrous effects on corn yields.

Corn yields may be reduced by as much as 40 percent when visible wilting occurs on four consecutive days at the time of silk emergence. Studies have also shown that severe drought during the pod-filling stage causes similar yield reductions in soybeans.

Increasing numbers of farmers are installing irrigation systems to prevent the detrimental effects of water deficiency. Some years of below-normal summer rainfall and other years of erratic rainfall distribution throughout the season have contributed to the increase. As other yield-limiting factors are eliminated, adequate water becomes increasingly important to assure top yields.

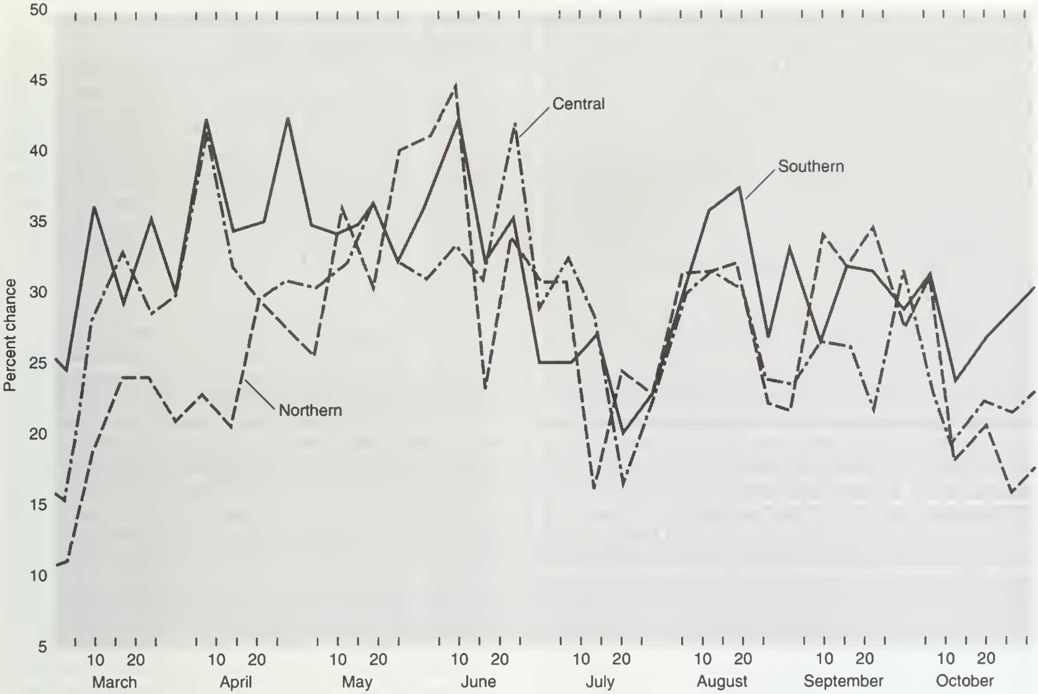


Figure 14.04. Chance of at least one inch of rain in one week.

Most of the development of irrigation systems has occurred on sandy soils or other soils with correspondingly low levels of available water. Some installations have been made on deeper, fine-textured soils, and other farmers are considering irrigation of such soils.

The decision to irrigate

The need for an adequate water source cannot be overemphasized when one is considering irrigation. If a producer is convinced that an irrigation system will be profitable, an adequate source of water is necessary. Such sources do not now exist in many parts of the state. Fortunately, underground water resources are generally good in the sandy areas where irrigation is most likely to be needed. A relatively shallow well in some of these areas may provide enough water to irrigate a quarter section of land. In some areas of Illinois, particularly the northern third, deeper wells may provide a relatively adequate source of irrigation water.

Some farmers pump their irrigation water from streams, a relatively good and economical source, if the stream does not dry up in a droughty year. Impounding surface water on an individual farm is also possible in some areas of the state, but this water source is practical only for small acreages. However, an appreciable loss may occur both from evaporation and from seepage into the substrata. Generally, 2 acre-inches of water should be stored for each acre-inch actually applied to the land.

To make a one-inch application on one acre (one acre-inch), 27,000 gallons of water are required. A flow of 450 gallons per minute will give one acre-inch per hour. Thus a 130-acre, center-pivot system with a flow of 900 gallons per minute can apply one inch of water over the entire field in 65 hours of operation. Because some of the water is lost to evaporation and some may be lost from deep percolation or runoff, the net amount added will be less than one inch.

The Illinois State Water Survey and the Illinois State Geological Survey (both located at Urbana) can provide information about the availability of irrigation water. Submit a legal description of the site planned for development of a well and request information regarding its suitability for irrigation well development. Once you decide to drill a well, the Water Use Act of

1983 requires you to notify the local Soil and Water Conservation District office if the well is planned for an expected or potential withdrawal rate of 100,000 gallons or more per day. There are no permit requirements or regulatory provisions.

An amendment passed in 1987 allows Soil and Water Conservation districts to limit the withdrawals from large wells if domestic wells meeting state standards are affected by localized drawdown. The legislation currently affects Kankakee, Iroquois, Tazewell, and McLean counties.

The Riparian Doctrine, which governs the use of surface waters, states that one is entitled to a reasonable use of the water that flows over or adjacent to his or her land as long as one does not interfere with someone else's right to use the water. No problem results as long as water is available for everybody. But when the amount of water becomes limited, legal determinations become necessary as to whether one's water use interferes with someone else's rights. It may be important to establish a legal record to verify the date on which the irrigation water use began.

Assuming that it will be profitable to irrigate and that an assured supply of water is available, how do you find out what type of equipment is available and what is best for your situation? University representatives have discussed this question in various meetings around the state, although they cannot design a system for each individual farm. Your county Extension adviser can provide lists of dealers located in and serving Illinois. This list includes the kinds of equipment each dealer sells, but it will not supply information about the characteristics of those systems.

We suggest that you contact as many dealers as you wish to discuss your individual needs in relation to the type of equipment they sell. You will then be in a much better position to determine what equipment to purchase.

Subsurface irrigation

Subirrigation can offer the advantages of good drainage and irrigation using the same system. During wet periods, the system provides drainage to remove excess water. For irrigation, water is forced back into the drains and then into the soil.

This method is most suitable for land areas where the slope is less than 2 percent, with either a relatively high water table or an impermeable layer at 3 to 10 feet below the surface. The impermeable layer ensures that applied water will remain where needed and that a minimum quantity of water will be sufficient to raise the water table.

The free water table should be maintained at 20 to 30 inches below the surface. This level is controlled and maintained at the head control stands, and water is pumped accordingly. In the event of a heavy rainfall, pumps must be turned off quickly and the drains opened. As a general rule, to irrigate during the growing season, you must deliver a minimum of 5 gallons per minute per acre.

The soil should be permeable enough to allow rapid water movement, so that plants are well supplied in peak consumption periods. Tile spacing is a major factor in the cost of the total system and is perhaps the most important single variable in its design and effectiveness. Where subirrigation is suitable, the optimum system will have closer drain spacings than a traditional drainage system.

Irrigation for double cropping

Proper irrigation can eliminate the most serious problem in double-cropping: inadequate water to get the second crop off to a good start. No part of Illinois has better than a 30 percent chance of getting an inch or more of rain during any week in July and most weeks in August. With irrigation equipment available, double-crop irrigation should be a high priority. If one is considering irrigating, the possibility of double-cropping should be taken into account in making the decision about irrigation. Soybeans planted at Urbana on July 6 following a wheat harvest have yielded as much as 38 bushels per acre with irrigation. In Mason County, soybeans planted the first week in July have yielded as much as 30 bushels per acre with irrigation.

While it may be difficult to justify investing in an irrigation system for double-cropping soybeans alone, the potential benefits from irrigating other crops may make the investment worthwhile. Some farmers report that double-cropping is a top priority in their irrigation programs.

Fertigation

The method of irrigation most common in Illinois, the overhead sprinkler, is the one best adapted to applying fertilizer along with water. Fertigation permits nutrients to be applied to the crop as they are needed. Several applications can be made during the growing season with little if any additional application cost. Nitrogen can be applied in periods when the crop has a heavy demand for both nitrogen and water. Corn uses nitrogen and water most rapidly during the 3 weeks before tasseling. About 60 percent of the nitrogen needs of corn must be met by silking time. Generally, nearly all the nitrogen for the crop should be applied by the time it is pollinating, even though some uptake occurs after this time. Fertilization through irrigation can be a convenient and timely method of supplying part of the plant's nutrient needs.

In Illinois, fertigation appears to be best adapted to sandy areas where irrigation is likely to be needed even in the wettest years. On finer-textured soils with high water-holding capacity, nitrogen might be needed even though water is adequate. Neither irrigating just to supply nitrogen nor allowing the crop to suffer for

lack of nitrogen is an attractive alternative. Even on sandy soils, only part of the nitrogen should be applied with irrigation water; preplant and sidedress applications should provide the rest of it.

Other problems associated with fertigation can only be mentioned here. These include (1) possible lack of uniformity in application; (2) loss of ammonium nitrogen by volatilization in sprinkling; (3) loss of nitrogen and resultant groundwater contamination by leaching if overirrigation occurs; (4) corrosion of equipment; and (5) incompatibility and low solubility of some fertilizer materials.

Cost and return

The annual cost of irrigating field corn with a center-pivot system in Mason County was estimated in 1987 to vary from $95 to $140 per acre. The lower figure is for a leased low-pressure system with a 50-horsepower electric motor driving the pump. The higher figure is for a purchased high-pressure system with a 130-horsepower diesel engine. Additional costs associated with obtaining a yield large enough to offset the cost of irrigation were estimated to be about $30 per acre per year, for a total irrigation cost of $125 to $170 per acre per year. The total investment for the purchased high-pressure irrigation system, including pivot, pump and gear head, diesel engine, and a 100-foot well, amounted to $450 per acre. If the low-pressure system were purchased, the total investment for the system, including pivot, pump, electric motor, and a 100-foot well, would be $400.

Irrigation purchases should be based on sound economics. The natural soil-water storage capacity for some soils in Illinois is too good to warrant supplemental irrigation. Based on the assumed fixed and variable costs of about $110 per acre per year, it would require an annual yield differential of about 50 bushels of corn ($2.20 a bushel) or 18 bushels of soybeans ($6.00 a bushel) to break even (Table 14.01). For irrigation to pay off, these yield differentials would have to be met on the average, over the 10- to 15-year life of the irrigation system. Some of the deep, fine-textured soils in Illinois simply would not regularly support these yield increases.

Table 14.01. Break-Even Yield Increase Needed to Cover Fixed and Variable Irrigation Costs

Corn price per bushel	Yield increase in bushels	Soybean price per bushel	Yield increase in bushels
$1.50	67	$4.75	21
1.70	59	5.00	20
1.90	53	5.25	19
2.10	48	5.50	18
2.30	43	5.75	17
2.50	40	6.00	17
2.70	37	6.25	16
2.90	34	6.50	15

Irrigation scheduling

Experienced irrigators have developed their own procedures for scheduling applications, whereas beginners may have to determine timing and rates of application before they feel prepared to do so. Irrigators generally follow one of two basic scheduling methods, each of which has many variations.

The first method involves measuring soil water and plant stress by (1) taking soil samples at various depths with a soil probe, auger, or shovel and then measuring or estimating the amount of water available to the plant roots; or (2) inserting instruments such as tensiometers or electrical resistance blocks into the soil to desired depths and then taking readings at intervals; or (3) measuring or observing some plant characteristics and then relating them to water stress.

Although in theory the crop can utilize 100 percent of the water that is available, the last portion of that water is not actually as available as the first water that the crop takes from the soil. Much like a half-wrung-out sponge, the remaining water in the soil following 50 percent depletion is more difficult to remove than the first half of the plant-available water.

The 50 percent depletion figure is often used to schedule irrigation. For example, if a soil holds 3 inches of plant-available water in the root zone, then we could allow 1½ inches to be used by the crop before replenishing the soil water with irrigation.

Soil samples

Estimating when the 1½ inches is used, or when 50 percent depletion occurs, can be done by a number of methods. One of the simplest is to estimate the amount of depletion by the "feel" method, which involves taking a sample from various depths in the active root zone with a spade, soil auger, or soil probe. It is important to dig a shallow hole to see how the soil looks at 6 to 12 inches early in the irrigation season. As the rooting depth extends to 3 feet, it may be wise to inspect a soil sample from the 9- to 18-inch level and another from the 24- to 30-inch level. Observing only the surface can be misleading on sandy soils because the top portion dries fairly quickly in the summer. To use this method of sampling, follow the guidelines shown in Table 14.02 to identify the depletion range you are in.

Tensiometers

Tensiometers are most suitable for sandy or loamy soils because the changes in soil-water content can be adequately described by the range of soil moisture tension (SMT) in which they operate. As plant roots dry the soil, SMT increases and water is pulled from the tensiometer into the surrounding soil, thereby increasing the reading on the vacuum gauge. After irrigation or rainfall, water replenishes the dry soil and SMT decreases. The vacuum developed in the tensiometer pulls water back through the porous ceramic

Table 14.02. Behavior of Soil at Selected Soil-Water Depletion Amounts

Available water remaining in the soil	Soil type	
	Sands	Loamy sand/sandy loam
Soil saturated, wetter than field capacity	Free water appears when soil ball is squeezed	Free water appears when soil ball is squeezed
100% available (field capacity)	When soil ball is squeezed, wet outline on hand but no free water	When soil ball is squeezed, wet outline on hand but no free water
75 to 100%	Sticks together slightly	Forms a ball that breaks easily
50 to 75%	Appears dry; will not form a ball	Appears dry; will not form a ball
Less than 50%	Flows freely as single grains	Flows freely as grains with some small aggregates

tip, and the dial gauge reading decreases. By responding to both wetting and drying, a tensiometer can yield information on the effect of crop transpiration or water additions to soil-water status.

A tensiometer must be installed carefully to ensure meaningful readings. Improper use may be worse than not using a tensiometer — because false readings can result in poorly timed irrigation. Before use, each tensiometer assembly must be soaked in water overnight; then the bubbles and dissolved gases must be removed from the water within the tube and ceramic cup. This procedure can be done by using boiled water and a small suction pump that is available from tensiometer manufacturers.

The tensiometer should be installed by creating a hole with a soil probe to within 3 to 4 inches of the desired depth, then pounding a rod with a rounded end to the final depth. The rod tip should be shaped like the tensiometer tip to ensure a good, porous cup-to-soil contact. Placement of tensiometers should be made according to two principles: (1) the tensiometer should be readily accessible if it is to be used; and (2) field placement of tensiometers should be made to stagger the readings throughout the irrigation cycle.

Tensiometers are available in lengths ranging from 6 inches to 4 feet. The length required depends on the crop grown, with lengths chosen to gain accurate information in the active root zone. For shallow-rooted vegetable crops, a single tensiometer per station, at a 6- to 9-inch depth, may be sufficient. Multiple-depth stations for corn or soybeans will allow you to track the depletion and recharge of soil water at several depths throughout the season. Because the active root zone shifts as the plant matures, water extraction patterns change as well. If you want to go with a single depth station, refer to Table 14.03 for the proper depths of placement.

Table 14.03. Tensiometer Placement Depth for Selected Crops

	Depth, inches	Depth, centimeters
Soybeans	18	46
Corn	12	30
Snap beans	9	23
Cucumbers	9	23

Tensiometers may require servicing if SMT increases to more than 80 centibars. At this tension, air enters the porous cup and the vacuum is broken. Tensiometers that have failed in this manner can be put back into service by filling them with deaerated water. Servicing can be done without removing the tensiometer from the soil. If proper irrigation levels are maintained, the SMT should not rise to levels sufficient to break the vacuum.

Moisture blocks

Moisture blocks (sometimes referred to as electrical resistance blocks or gypsum blocks) are small blocks of gypsum with two embedded electrodes. The block operates on the principle that the electrical resistance of the gypsum is affected by water content.

When saturated, the gypsum block has low electrical resistance. As it dries, the electrical resistance increases. The moisture blocks are placed in the soil and electrical leads coming from the embedded electrodes are allowed to protrude from the soil surface. These leads are connected to a portable instrument that includes an electrical resistance meter and a voltage source.

When a reading is desired, a voltage is applied and the resulting reading is recorded. The reading is converted to a soil-water content by using a predetermined calibration curve relating resistance to water content. Soil moisture blocks work well in fine- and medium-textured soils and are not recommended for sandy soils. The increase in fine-textured soil irrigation in Illinois, particularly for seed corn, may prompt an increase in the use of moisture blocks. As with tensiometers, a good soil contact is absolutely necessary for meaningful readings. Soil water must be able to move in and out of the blocks as if the blocks were part of the soil. Any gap between the block and the surrounding soil will prevent this movement.

Another method of scheduling, frequently called the "checkbook method," involves keeping a balance of the amount of soil water by measuring the amount of rainfall and then measuring or estimating the amount of water lost from crop use and evaporation. When the water drops to a certain level, the field is irrigated. Computer techniques are also available for estimating water loss, computing the water balance, and predicting when irrigation is necessary.

Management requirements

Irrigation will provide maximum benefit only when it is integrated into a high-level management program. Good seed or plant starts of proper genetic origin planted at the proper time and at an appropriate population, accompanied by optimum fertilization, good pest control, and other recommended cultural practices are necessary to assure the highest benefit from irrigation.

Farmers who invest in irrigation may be disappointed if they do not manage to irrigate properly. Systems are so often overextended that they cannot maintain adequate soil moisture when the crop requires it. For example, a system may be designed to apply 2 inches of water to 100 acres once a week. In two or more successive weeks, soil moisture may be limiting, with potential evapotranspiration equaling 2 inches per week. If the system is used on one 100-acre field one week and another field the next week, neither field may receive much benefit, especially if water stress comes at a critical time, such as during pollination of corn or soybean seed development. Inadequate production of marketable products may result.

Currently we suggest that irrigators follow the cultural practices they would use for the most profitable yield in a year of ideal rainfall. In many parts of the state, 1975, 1981, and 1982 were such years. If a farmer's yield is not already appreciably above the county average for that particular soil type, he or she needs to improve management of other cultural factors before investing in an irrigation system.

The availability of irrigation on the farm permits the use of optimum production practices every year. If rains come as needed, the investment in irrigation equipment will have been unnecessary that year, but no operating costs will be involved. When rainfall is inadequate, however, the yield potential can still be realized with irrigation.

Chapter 15.

1995 Weed Control for Corn, Soybeans, and Sorghum

This guide is based on the results of research conducted by the University of Illinois Agricultural Experiment Station, other experiment stations, and the U.S. Department of Agriculture (USDA). The soils, crops, and weed problems of Illinois have been given primary consideration.

The user should have an understanding of cultural and mechanical weed control. These practices change little from year to year, so this text will focus on making practical, economical, and environmentally sound decisions regarding herbicide use.

Most of the suggestions in this guide are intended primarily for ground applications. For aerial applications, such factors as amount of water and adjuvant may differ.

Precautions

The benefits of chemical weed control must be weighed against the potential risks to crops, people, and the environment. Discriminate use should minimize exposure of humans and livestock, as well as desirable plants. Risks can be reduced by observing current label precautions.

Current label

Precautions and directions for use may change. Herbicides classified as restricted-use pesticides (RUP) must be applied only by certified applicators (Table 15.01). Their use may be restricted because of toxicity or environmental hazards. Toxicity is indicated by the signal word on the label.

Signal word

Heed the accompanying precautions. The signal word for herbicides discussed in this guide is given in Table 15.01. "Danger—Poison" and "Danger" indicate high toxicity hazards, while "Warning" indicates moderate toxicity. Always use personal protective equipment (PPE) as specified on the label for handling and application. Keep persons or animals not directly involved in the operation out of the area. Observe reentry intervals (REI) as specified on the label. Use special drift precautions near residential areas.

Environmental hazards

Groundwater advisories (Table 15.01) must be observed, especially on sandy soils with a high water table. The threat of toxicity to fish and wildlife is indicated under "Environmental Hazards" on the label. Hazards to endangered species may be indicated.

Proper herbicide use

Apply only to approved crops at the proper rate and time. Illegal residues can result from overapplication or wrong timing. Observe the recommended harvesting or grazing intervals after treatment.

Proper equipment use

Make sure that spray tanks are clean and free of other pesticide residues. Many herbicide labels provide cleaning suggestions, which are particularly important when spraying different crops with the same sprayer and especially when using postemergence herbicides. Correctly calibrate and adjust the sprayer before adding the herbicide to the tank.

Proper drift precautions

Spray only on calm days or when the wind is very light. Make sure the wind is not moving toward areas of human activity, susceptible crops, or ornamental

Table 15.01. Herbicide and Herbicide Premix Names and Restrictions

Trade name(s)	Common (generic) name(s)	Restricted-use pesticide[a]	Groundwater advisory[b]	Signal word[c]
AAtrex, atrazine	Atrazine	Yes	Yes	Caution
Accent	Nicosulfuron	—	—	Caution
Assure II	Quizalofop	—	—	Caution
Banvel	Dicamba	—	—	Warning
Basagran	Bentazon	—	—	Caution
Beacon	Primisulfuron	—	—	Caution
Bicep, Bicep Lite	Metolachlor + atrazine	Yes	Yes	Caution
Bladex	Cyanazine	Yes	Yes	Warning
Blazer	Acifluorfen	—	—	**Danger**
Broadstrike + Dual	Flumetsulam + metolachlor	—	Yes	Warning
Broadstrike + Treflan	Flumetsulam + trifluralin	—	Yes	**Danger**
Broadstrike Pre/PPI	Flumetsulam + clopyralid	—	Yes	**Danger**
Bronco	Alachlor + glyphosate	Yes	Yes	**Danger**
Buctril	Bromoxynil	—	—	Warning
Buctril + Atrazine	Bromoxynil + atrazine	Yes	Yes	Caution
Bullet	Alachlor + atrazine	Yes	Yes	Caution
Butyrac 200	2,4-DB	—	—	**Danger**
Canopy, Preview	Metribuzin + chlorimuron	—	Yes	Caution
Clarity	Dicamba	—	—	Caution
Classic	Chlorimuron	—	—	Caution
Cobra	Lactofen	—	—	**Danger**
Command	Clomazone	—	—	Warning
Commence	Clomazone + trifluralin	—	—	Warning
Concert, Synchrony STS	Chlorimuron + thifensulfuron	—	—	Caution
Contour	Imazethapyr + atrazine	Yes	Yes	Caution
Cycle	Metolachlor + cyanazine	Yes	Yes	Caution
Dual, Dual II	Metolachlor	—	Yes	Caution
Eradicane	EPTC + safener	—	—	Caution
Extrazine II	Cyanazine + atrazine	Yes	Yes	Warning
Freedom	Alachlor + trifluralin	Yes	Yes	Warning
Frontier	Dimethenamid	—	Yes	Warning
Fusilade DX	Fluazifop	—	—	Caution
Fusion	Fluazifop + fenoxaprop	—	—	Caution
Galaxy, Storm	Bentazon + acifluorfen	—	—	**Danger**
Gramoxone Extra	Paraquat	Yes	—	**Danger—Poison**
Harness	Acetochlor + safener	Yes	Yes	Warning
Harness Xtra	Acetochlor + atrazine	Yes	Yes	Caution
Laddok S-12	Bentazon + atrazine	Yes	Yes	**Danger**
Lasso EC	Alachlor	Yes	Yes	**Danger**
Lexone	Metribuzin	—	Yes	Caution
Lorox	Linuron	—	—	Caution
Lorox Plus	Linuron + chlorimuron	—	—	Warning
Marksman	Dicamba + atrazine	Yes	Yes	Caution
Many trade names	2,4-D amine	—	—	**Danger**
Many trade names	2,4-D ester	—	—	Caution
Micro-Tech, Partner	Alachlor	Yes	Yes	Caution
Pinnacle	Thifensulfuron	—	—	Caution
Poast Plus	Sethoxydim	—	—	Caution
Princep, Simazine	Simazine	—	Yes	Caution
Prowl, Pentagon	Pendimethalin	—	—	Warning
Pursuit	Imazethapyr	—	—	Caution
Pursuit Plus	Pendimethalin + imazethapyr	—	—	Caution
Reflex	Fomesafen	—	—	Warning
Resolve	Imazethapyr + dicamba	—	No	Warning
Roundup	Glyphosate	—	—	Warning
Salute	Metribuzin + trifluralin	—	Yes	Caution
Scepter	Imazaquin	—	—	Caution
Select	Clethodim	—	—	Warning
Sencor	Metribuzin	—	Yes	Caution
Sonalan	Ethalfluralin	—	—	Warning
Squadron	Imazaquin + pendimethalin	—	—	**Danger**
Stinger	Clopyralid	—	Yes	Caution
Surpass	Acetochlor + safener	Yes	Yes	Warning
Surpass 100	Acetochlor + atrazine	Yes	Yes	**Danger**
Sutan+	Butylate + safener	—	—	Caution
Synchrony STS	Chlorimuron + thifensulfuron	—	—	Caution
Tornado	Fluazifop + fomesafen	—	—	Warning
Tough	Pyridate	—	—	Caution
Treflan, Tri-4, Trific	Trifluralin	—	—	Warning
Tri-Scept	Imazaquin + trifluralin	—	—	**Danger**
Turbo	Metribuzin + metolachlor	—	Yes	Caution

[a] To be applied by licensed applicator.
[b] Special precautions in sandy soils.
[c] Signal word = Toxicity signal; indicates need for extra precautions. The signal words "Danger" and "Warning" often indicate pesticides that can irritate skin and eyes, necessitating protective clothing, gloves, and goggles or face shield.

plants. Nearby residential areas and fields of edible horticultural crops deserve particular attention. *Use special precautions with Gramoxone Extra, Command, Banvel, Clarity, Marksman, Resolve, and 2,4-D,* as symptoms of injury have occurred far from the application site.

Precautions to protect the crop

Avoid applying a herbicide to crops under stress or predisposed to injury. Crop sensitivity varies with size of the crop and climatic conditions, as well as previous injury from plant diseases, insects, or chemicals.

Proper recropping interval

Failure to observe the proper recropping intervals may result in carryover injury to the next crop. Soil texture, organic matter, and pH may affect herbicide persistence. Atrazine used in corn or milo can carry over and injure susceptible follow crops. Many soybean herbicides have special recropping restrictions. Check Table 15.02 and current labels for recropping restrictions.

Proper storage

Promptly return unused herbicides to a safe storage place. Pesticides should be stored in their original, labeled containers in a secure place away from unauthorized people (particularly children) and livestock and their food or feed.

Proper container disposal

Liquid containers should be pressure- or triple-rinsed. Properly rinsed containers can be recycled or may be accepted by some sanitary landfills. Haul paper containers to a sanitary landfill or burn them in an approved manner. If possible, use mini-bulk returnable containers.

Cultural and mechanical control

Good cultural practices that aid in weed control include adequate seedbed preparation, adequate fertilization, crop rotation, planting on the proper date, use of the optimum row width, and seeding at the rate required for optimum stands.

Planting in relatively warm soil can help the crop emerge quickly and compete better with weeds. Good weed control during the first 3 to 5 weeks is extremely important for both corn and soybeans. If weed control is adequate during that period, corn and soybeans will usually compete quite well with most of the weeds that begin growing later.

Narrow rows will shade the centers faster and help the crop compete better with the weeds. If herbicides alone cannot give adequate weed control, however, then keep rows wide enough to allow for cultivation.

If adequate rainfall does not occur after the application of a preemergence or preplant herbicide, use the rotary hoe after weed seeds have germinated but before most weeds have emerged. Operate it at 8 to 12 miles per hour, and weight it enough to stir the soil and kill the tiny weeds. Rotary hoeing also aids crop emergence if the soil is crusted.

Row cultivators also should be used while weeds are small. Throwing soil into the row can help smother small weeds. Cultivate shallowly to prevent injury to crop roots.

Herbicides can provide a convenient and economical means of early weed control and allow for delayed and faster cultivation. Furthermore, unless the soil is crusted, it may not be necessary to cultivate some fields if herbicides are adequately controlling weeds.

Herbicide incorporation

Sutan+, Eradicane, Command, Treflan, Sonalan, and premixes containing their active ingredients are incorporated after application to minimize surface loss from volatilization and/or photodecomposition. Many other soil-applied herbicides may be incorporated to minimize dependence on timely rainfall or to improve control of certain weed species.

Incorporation should place the herbicide uniformly throughout the top 1 to 2 inches of soil for the best control of small-seeded annual weeds that germinate at shallow depths. Slightly deeper placement is recommended for some herbicides and may improve the control of certain weeds from deep-germinating seed under relatively dry conditions. Incorporating too deeply, however, tends to dilute the herbicide and may reduce its effectiveness. The commonly used incorporation tools distribute most of the herbicide into the soil to about one-half the depth of operation. Thus, for most herbicides, the suggested depth of operation is 3 to 4 inches for most tillage tools.

Thorough incorporation with ground-driven implements usually requires two passes. If the first pass sufficiently covers the herbicide to prevent surface loss, the second pass can be delayed until immediately before planting. Single-pass incorporation may be adequate with some herbicides and some equipment, especially if rotary hoeing, cultivation, or subsequent herbicide treatment is used to improve weed control.

For herbicides with long residual activity, accurate application and uniform distribution can be very important for avoiding carryover problems.

The depth and thoroughness of incorporation depend upon the type of equipment used, the depth and speed of operation, the texture of the soil, and the amount of soil moisture. Field cultivators and tandem disks are commonly used for incorporation; however, disk-chisels and other combination tools are also used.

Field cultivators

Field cultivators are frequently used for herbicide incorporation. They should have three or more rows

Table 15.02. Herbicide Recropping Restrictions—Months

Herbicide[a]	pH	Corn	Milo	Wheat	Oats	Rye	Alfalfa	Clover	Soybeans
Accent	. . .	AT	10[b]	4	8	4	10	10[b]	10
Atrazine	<7.2	AT	AT	15	21	21	21	21	10[c]
Banvel[d]	. . .	AT	0.5	1	1	1	4	4	0.5
Beacon	. . .	0.5	8	3	8	3	8	18	8
Bicep	. . .	AT	AT[e]	15	15	15	18	18	10[c]
Broadstrike + Dual	. . .	AT	18	4.5	4.5	4.5	4	26	AT
Broadstrike + Treflan	. . .	8	18	4	12	4	4	20	AT
Broadstrike Pre/PPI	. . .	AT	12	4	4	4	10.5	26	10.5
Buctril/atrazine	. . .	AT	AT	15	21	15	21	21	10[c]
Bullet, Lariat	. . .	AT	AT[e]	15	21	15	21	21	10[c]
Canopy[f]	≤6.8	10	12	4	18, BA	18, BA	10	12	AT
Classic, Concert	. . .	9	9[g]	3	3	3	9[g]	9[g]	AT
Command	. . .	9	9	12	16	16	16	16	AT
Commence	. . .	9	12	12	16	16	16	16	AT
Cycle	. . .	AT	AT[e]	4.5	4.5	4.5	4	9	9
Dual	. . .	AT	AT[e]	4.5	4.5	4.5	4	9	AT
Extrazine II	. . .	AT	AT	15	15	15	18	18	10[c]
Guardsman	. . .	AT	NY	15	21	15	15	15	NY
Harness	. . .	AT	NY	NL	NL	NL	NL	NL	NY
Laddok	. . .	AT	AT	9	9	9	18	18	10[c]
Lexone	. . .	4	12	4	12	12	4	12	AT
Lorox Plus	≤6.8	10	10	4	4	4	10	12	AT
Marksman	. . .	AT	AT	10	10	10	18	18	10[c]
Passport	. . .	8.5	18	4	18	18	18	18	AT
Preview	≤6.8	10	12	4	BA	BA	10	12	AT
Princep	. . .	AT	12	15	21	21	21	21	10[c]
Pursuit	. . .	8.5	18	4	18	4	18	18	AT
Pursuit Plus	. . .	8.5	18	4	18	18	18	18	AT
Reflex	. . .	10	18	4	4	4	18	18	AT
Salute	. . .	4	12	4	12	12	4	12	AT
Scepter—Region 3									
⅓ pt/acre	. . .	11	11	4[h]	4	18	18	18	AT
⅔ pt/acre	. . .	18	11	16	16	18	18	18	AT
Scepter[i]—Region 2	. . .	11[h]	11	4[h]	11	18	18	18	AT
Sencor	. . .	4	12	4	12	12	4	12	AT
Squadron[i]—Region 2	. . .	11[h]	11	4[h]	11	18	18	18	AT
Stinger	. . .	AT	AT	AT	AT	AT	12	18	10.5
Surpass	. . .	AT	NY	4	NL	NL	NL	NL	NY
Surpass 100	. . .	AT	NY	15	NL	NL	NL	NL	NY
Synchrony STS	. . .	9	11, BA	3	3	3	11, BA	11, BA	AT
Tri-Scept[i]—Region 2	. . .	11[h]	11	4[h]	11	18	18	18	AT
Turbo	. . .	8	12	4.5	12	12	12	12	AT

. . . = no pH restrictions; AT = any time (no restrictions); BA = bioassay after 10 months; NY = next year (spring); NL = not labeled.
[a] The following have no labeled rotational restrictions: Banvel, Basagran, Bladex, Blazer, Bronco, Butyrac 200, Clarity, Cobra, Eradicane, 2,4-D, Galaxy, Gramoxone Extra, Lasso, Poast Plus, Roundup, Sonalan, Storm, Sutan, and Treflan, except for Eradicane, 2,4-D, and Sutan+, which have replanting limits for soybeans.
[b] 18 months if pH > 6.5.
[c] If applied before June 10.
[d] From the between-cropping label.
[e] Seed protectant needed.
[f] Reduced-rate label for Midwest states.
[g] 15 months if pH > 7.
[h] 15-inch annual rainfall restriction or use imidazolinone-resistant or -tolerant (IMI) corn hybrids.
[i] Region 2 only on Scepter label (approximately southern two-thirds of Illinois). See label for Region 3 use.

of shanks with an effective shank spacing of no more than 8 to 9 inches (a spacing of 24 to 27 inches on each of three rows). The shanks may be equipped with points or sweeps; however, sweeps give better incorporation, especially when soil conditions are a little too wet or dry for optimum soil flow and mixing. Sweeps for C-shank cultivators should be at least as wide as the effective shank spacing.

The recommended operating depth for the field cultivator is 3 to 4 inches. It is usually sufficient to operate the field cultivator only deep enough to remove tractor tire depressions. The ground speed should be at least 6 miles per hour. The field cultivator must be operated in a level position so that the back shanks are not operating in untreated soil, which would result in streaked weed control. Two passes are recommended to obtain uniform weed control with most herbicides. However, single-pass incorporation may sometimes be adequate for some herbicides with certain equipment and soil conditions. If single-pass incorporation is preferred, the use of wider sweeps or narrower spacing with a three- to five-bar harrow or rolling baskets pulled behind will increase the probability of obtaining adequate weed control.

Tandem disks

Tandem disk harrows invert the soil and usually place the herbicide deeper in the soil than most other incorporation tools. Tandem disks used for herbicide incorporation should have disk blade diameters of 20 inches or less and blade spacings of 7 to 9 inches. Larger disks are considered primary tillage tools and should not be used for incorporating herbicides. Spher-

ical disk blades give better herbicide mixing than do conical disk blades.

Tandem disks usually place most of the herbicide in the top 50 to 60 percent of the operating depth. For most herbicides, the suggested operating depth is 3 to 4 inches. Two passes are recommended to obtain uniform mixing with a double disk. A leveling device (harrow or rolling baskets) should be used behind the disk to obtain proper mixing. Recommended ground speeds are usually between 4 and 6 miles per hour. The speed should be sufficient to move the soil the full width of the blade spacing. Lower speeds can result in herbicide streaking.

Combination tools

Several tillage tools combine disk gangs, field cultivator shanks, and leveling devices. Many of these combination tools can handle large amounts of surface residue without clogging and yet leave considerable crop residue on the soil surface for erosion control. Results indicate that these combination tools may provide more uniform one-pass incorporation than a disk or field cultivator, but one pass with them is generally no better than two passes with the disk or field cultivator.

Chemical weed control

Plan your weed-control program to fit your soils, tillage program, crops, weed problems, and farming operations. Good herbicide performance depends on the weather and on wise selection and application. Your decisions about herbicide use should be based on the nature and seriousness of your weed problems. The herbicide selectivity tables in this guide indicate the susceptibility of our most common weed species to herbicides.

Corn or soybeans may occasionally be injured by some of the herbicides registered for use on these crops. To reduce injury to crops, apply the herbicide uniformly, at the time specified on the label, and at the correct rate. (See the section below titled "Herbicide Rates.") Crop tolerance ratings for various herbicides are also given in the tables in this chapter. Unfavorable conditions such as cool, wet weather; delayed crop emergence; deep planting; seedling diseases; soil in poor physical condition; and poor-quality seed may contribute to crop stress and herbicide injury. Hybrids and varieties also vary in their tolerance to herbicides and environmental stress factors. Once injured by a herbicide, plants may be more prone to disease.

Crop planting intentions for next season must also be considered when selecting a herbicide program. Where atrazine or simazine is used, you should not plant fall- or spring-seeded small grains, small-seeded legumes and grasses, or vegetables the following year. If atrazine is applied after June 10, only corn or milo should be planted the following year. Be sure that the application of a herbicide such as Treflan, Canopy, Command, or Scepter is uniform and properly timed to minimize injury to wheat or corn following soybeans. Refer to the label for information about cropping sequence and appropriate intervals to allow between different crops. Table 15.02 provides a summary of some of the crop rotation restrictions.

Some herbicides have different formulations and concentrations under the same trade name. *No endorsement of any trade name is implied, nor is discrimination against similar products intended.*

Weed resistance to herbicides

One of the disadvantages of chemical weed control is that weeds can become resistant to herbicides. Herbicide resistance is not presently a major problem in Illinois, but it could become a problem without proper management. There are triazine-resistant pigweed, lambsquarters, and kochia and probably acetolactate synthase (ALS)–resistant water hemp in Illinois. The imidazolinones, sulfonylurea, and sulfonamide herbicides all have the same mode of action, inhibiting the ALS enzyme. These herbicides have good environmental and economic profiles so they have become quite popular. Their repeated use has the potential to increase the weed resistance problem in Illinois.

Certain management strategies will help deter the development of herbicide-resistant weeds:

(1) Scout fields regularly to identify resistant weeds. Monitor changes in weed populations to restrict the spread of herbicide-resistant weeds.

(2) Rotate herbicides with different modes of action. Do not make more than two consecutive applications of herbicides (whether within the same year or between years) with the same mode of action against the same weed. Instead, include other effective management strategies for weed control. This is critical when using herbicide-resistant crops.

(3) Use multiple modes of action (tank-mix, premix, or sequential) that will effectively control potentially resistant weeds.

(4) Where practical, use rotary hoeing and cultivation to control weed escapes. If necessary, use hand weeding to minimize the spread of herbicide-resistant weeds.

(5) Be aware that resistant weeds can spread from total vegetation control (TVC) programs used along highway, railroad, or utility right-of-way areas near your farm.

For further information on the causes of herbicide resistance and strategies to minimize it, visit your Extension office or see chapter 20, "Weed Resistance to Herbicides" in the current *Illinois Agricultural Pest Management Handbook.*

Herbicide combinations

Herbicide combinations can control more weed species, reduce carryover, and reduce crop injury. Nu-

merous combinations of herbicides are sold as premixes, and some are tank-mixed. Registered tank mixes are shown in the tables in this chapter. Tank-mixing allows you to adjust the ratio of herbicides to fit local weed and soil conditions, while premixes may overcome some of the compatibility problems found with tank-mixing. When using a tank mix, you must follow restrictions for all products used in the combination.

Problems may occur when mixing emulsifiable concentrate (EC) formulations with wettable powder (W), liquid flowable (L), or dry flowable (DF) formulations. These problems can sometimes be prevented by using proper mixing procedures. If you are using a liquid fertilizer carrier, check the herbicide label, since most labels specify testing to determine compatibility. Fill tanks at least one-fourth full with water or liquid fertilizer before adding herbicides that are suspended. If needed, a compatibility agent is used at 1 to 4 pints per 100 gallons of spray mix; it should be added to the carrier before the herbicide(s). Wettable powders, dry flowable, and liquid flowable concentrates should be added to the tank and thoroughly mixed before adding emulsifiable concentrates. Emulsify concentrates by mixing with equal volumes of water before adding them to the tank. Empty and clean-spray tanks often enough to prevent accumulation of material on the sides and the bottom of the tank.

You can apply two treatments of the same herbicide (split application) or can use two different herbicides, provided such uses are registered. The use of one herbicide after another is referred to as a sequential or overlay treatment.

Herbicide rates

Herbicide rates vary according to the time and method of application, soil conditions, the tillage system used, and the seriousness of the weed infestation. Rates of individual components within a combination are usually lower than rates for the same herbicides used alone.

The rates for soil-applied herbicides usually vary with the texture of the soil and the amount of organic matter the soil contains. For sandy soils, the herbicide label may specify reducing the rate or not using at all if crop tolerance to the herbicide is marginal. Postemergence rates often vary depending upon the size and species of the weeds.

The rates given in this chapter are, unless otherwise specified, broadcast rates for the amount of formulated product. If you plan to band or direct herbicides, adjust the amount per crop acre according to the percent of the area actually treated. Herbicides may have several formulations with different concentrations of active ingredient. Be sure to read the label and make necessary adjustments when changing formulations.

Postemergence herbicide principles

Postemergence herbicides applied to growing weeds generally have foliar rather than soil action; however, some may have both. The rates and timing of applications are based on weed size and climatic conditions. Weeds can usually be controlled with lower application rates when they are small. Larger weeds often require higher herbicide rates. Herbicide penetration and action are usually greater with warm temperature and high relative humidity. Rainfall occurring too soon after application (0.5 to 8 hours, depending on the herbicide) can reduce weed control.

Translocated herbicides are most effective at lower spray volumes (5 to 20 gallons per acre), whereas contact herbicides require more complete coverage. Foliar coverage increases as water volume and spray pressure are increased. Spray nozzles that produce small droplets also improve coverage. For contact herbicides, 20 to 40 gallons of water per acre is often recommended for ground application, and a minimum of 5 gallons per acre is recommended for aerial application. Spray pressures of 30 to 60 psi are often suggested with flat-fan or hollow-cone nozzles to produce small droplets and improve canopy penetration. *These small droplets are quite subject to drift.*

Crop size limitations may be specified on the label to minimize crop injury and maximize weed control. If weeds are smaller than the crop, basal-directed sprays may minimize crop injury because they place more herbicide on the weeds than on the crop. If the weeds are taller than the crop, rope-wick or sponge-type applicators may be used to place the herbicide on top of the weeds and minimize contact with the crop. Follow the label directions and precautions for each herbicide.

The label may recommend adding a nonionic surfactant (NIS), a crop oil concentrate (COC), or an ammonium fertilizer adjuvant. Surfactants cause a spreading and wetting action by decreasing the surface tension of water, allowing the herbicide in a water carrier to spread over waxy or hairy leaf surfaces rather than forming droplets. Since more leaf surface is covered, more herbicide may be absorbed. In most postemergence herbicide applications, surfactants increase phytotoxic action. Surfactants may also contain fatty acids to improve penetration. The new organosilicone surfactants have tremendous spreading ability. Labels may specify that the NIS should contain a minimum of 75 to 85 percent active ingredient or to use a higher surfactant rate. NIS is usually applied at 0.5 to 2 pints per acre or 1/8 to 1/2 percent on a volume to volume basis.

Crop oil concentrates spread the herbicide across the leaf surface, keep the surface moist longer, and aid penetration into the cuticle. Oils generally have a greater postemergence effect than surfactants. COCs are phytobland oils with emulsifier (surfactant) added to allow better mixing with water. The oil may be of petroleum (POC) or vegetable (VOC) origin. Methylated seed oils are esters of fatty acids formulated to improve the performance of vegetable oils. POCs usually contain 83 to 85 percent oil and 15 to 17 percent emulsifier, while VOCs contain 85 to 93 percent

highly refined vegetable oil and 7 to 15 percent emulsifier. Most labels allow either POC or VOC, although a few, such as Assure II and Concert, specify POC only. COCs are used at 1 to 3 pints per acre or about 1 percent on a volume basis.

Ammonium fertilizer adjuvants are added to increase herbicide activity on weed species such as velvetleaf. Urea ammonium nitrate (UAN) solution, often referred to as 28 percent, is the most common fertilizer adjuvant, although ammonium polyphosphate (10-34-0) or ammonium sulfate (AMS) may also be allowed. UAN is usually used at 2 to 4 quarts per acre. Contact herbicide labels often specify that fertilizer adjuvants replace NIS or COC, while translocated herbicides usually specify UAN in addition to NIS or COC. Mixtures of ammonium salts plus surfactant are available where a combination is desired.

Drift reduction agents are added to the spray tank to reduce small droplet formation and thus reduce particle drift. The rate per 100 gallons of spray is 2 to 10 fluid ounces for concentrated forms and 2 to 4 quarts for dilute forms (those with a low percentage active ingredient).

Conservation tillage and weed control

Conservation tillage allows crop production while reducing soil erosion by protecting the soil surface with plant residue. Minimum or reduced tillage refers to any tillage system that leaves crop residue on the soil surface. This includes primary tillage with chisel plows or disks and the use of field cultivators, disks, or combination tools for secondary tillage. Mulch tillage is reduced tillage that leaves at least 30 percent of the soil surface covered with plant residue.

Ridge tillage and zero tillage are conservation tillage systems with no major tillage prior to planting. In ridge tillage, conditions are often ideal for banding preemergence herbicides because cultivation is a part of the system. "No-till" is actually slot tillage for planting with no overall primary tillage. No-till planting conserves moisture, soil, and fuel. It also allows timely planting of soybeans or sorghum after winter wheat harvest.

If tillage before planting is eliminated, undesirable existing vegetation at planting must be controlled with herbicides. The elimination or reduction of herbicide incorporation and row cultivation puts a greater reliance on chemical weed control. Greater emphasis may be placed on preplant or postplant soil-applied herbicides that are not incorporated or on foliar-applied herbicides.

Where primary tillage is minimized, soil residual herbicides applied several weeks before planting may reduce the need for a "knockdown" herbicide. However, early preplant (EPP) application may require additional preemergence or postemergence herbicides or cultivation for satisfactory weed control after planting. See the "Early Preplant Not Incorporated" sections for corn and soybeans for more details.

Corn and soybeans are the primary crops in Illinois, and they are often planted in rotation. Modern equipment allows successful no-till planting in corn and soybean stubble. The use of a disk or chisel plow on corn stubble may still provide adequate crop residue to meet mulch-till requirements. Herbicides are also available to allow a "total postemergence" weed control program, especially for soybeans.

Soybean stubble is often ideal for zero- or minimum-tillage production systems. Primary tillage is rarely needed, and the crop residue should not interfere with herbicide distribution. Early preplant application of preemergence herbicides or the use of postemergence herbicides can often provide adequate weed control.

The existing vegetation in corn and soybean stubble is often annual weeds. If the weeds are small, they can often be controlled before planting with herbicides that have both foliar and soil residual activity. For corn, these include atrazine or Bladex and their premixes. For soybeans, metribuzin (Sencor or Lexone), linuron (Lorox), and their premixes with chlorimuron (Preview, Canopy, or Lorox Plus) can be used. (See Table 15.03.) Foliar activity is enhanced with the addition of crop oil concentrate, nonionic surfactant, or 28 percent UAN. See the label for specific adjuvant recommendations.

Annual vegetation over 2 to 3 inches tall at planting may require a contact or a translocated herbicide (Table 15.03). Gramoxone Extra, Roundup, or Bronco can be used with most preemergence herbicides to control existing vegetation. To control broadleaf weeds, 2,4-D can be used prior to planting corn or no-till soybeans, and Banvel can be used prior to corn.

Annual cover crops in Illinois are hairy vetch, winter rye, and winter wheat. Hairy vetch, a winter annual, is easily controlled with 2,4-D or Banvel before planting corn. Winter rye or winter wheat can be controlled by Roundup prior to planting corn or soybeans. Spring oats are sometimes used as a temporary cover on set-aside land but are usually mowed or left to winterkill. Cover crops should be controlled prior to planting crops, but how early? If the season is dry, late control will deplete soil moisture for crop establishment, while if the season is wet, late control will help dry out the soil. Decomposing residue of small grain cover crops can sometimes inhibit corn seedlings.

Perennial sods require a different approach. During 1995-96, 40 percent of the Conservation Reserve Program (CRP) contracts will expire. It is estimated that 65 to 70 percent of the CRP acres in the Corn Belt will return to cropland. Many of these acres have been planted into perennial grass or legume sods. What is the best way to control sod species? What is the best timing for control and what are the best cropping choices? *Sods should be killed prior to planting crops into them* (Table 15.04).

Perennial grass sods were planted on much of the

Table 15.03. Control Ratings for No-Till Herbicides to Control Existing Vegetation

Herbicide	DBM	GFT	RYE	MTL	PLC	MUS	LBQ	CRW	GRW	SWD	DDL	HVC	RCV	ALF
Roundup	9	10	9	9	7	8	9	9	9	7	5	6	6	5
Roundup + 2,4-D	9	10	9	9	9	9	9	9	9	8	8	8	8	7+
Gramoxone	7	8	7	5	6	6	8	8	7	5	4	7	7	3
Gramoxone + atrazine	8	9	8	9	9	9	10	10	9	9+	6	8	7	4
2,4-D ester	0	0	0	8	8	9	9	10	8+	6	8+	8	8	6+
Banvel/Clarity	0	0	0	8	9	7	9	10	9	9+	8	9	9	8
2,4-D + Banvel	0	0	0	8	9	9	9	10	9	8	8	9	9	8
Marksman	6	5	3	9	9	8	10	10	9	9+	8	9	9	8
Atrazine	7	7	7	9	9	8	10	10	9	9+	4	7	5	3
Bladex	8	8	5	9	9	8	10	10	8	9	5	8	3	3
Extrazine II	8	8	7	9	9	8	10	10	8	9+	5	8	5	3
Canopy	5	5	3	8	9	8	9	9	7	8	7	5	6	3
Pursuit	3	8	2	4	6	8	6	6	6	8	4	2	3	0
Sencor, Lexone	6	5	4	6	8	8	9	7	7	8	6	3	6	3

DBM = downy brome, GFT = giant foxtail, RYE = rye or wheat cover, MTL = marestail (horseweed), PLC = prickly lettuce, MUS = mustards, LBQ = lambsquarters, CRW = common ragweed, GRW = giant ragweed, SWD = smartweeds, DDL = dandelion, HVC = hairy vetch, RCV = red clover, ALF = alfalfa sod.

In weed columns, 10 = 95 to 100% control, 9 = 85 to 95%, 8 = 75 to 85%, 7 = 65 to 75%, 6 = 55 to 65%, 5 and below = insignificant control, + = control at the higher end of the range. Boldface indicates acceptable control.

Table 15.04. Control of Perennial Grass and Legume Sods with Roundup or Gramoxone Extra

	Roundup rate (qt/acre)[a]		Roundup control rating[a]				Gramoxone Extra control rating (spring)	
			Fall		Spring			
Sod Species	Fall	Spring	1 qt/acre	2 qt/acre	1 qt/acre	2 qt/acre	Without triazine	With triazine[b]
Timothy	1.0	2.0	9	10	7	8	5	8
Bluegrass	1.0	1.5	9	10	8	9	7	9
Tall fescue	1.0	2.0[c]	7	8	6	7	5	7+
Quackgrass (sod)	1.5	2.0	9+	10	8+	10	5	7
Orchardgrass	1.5	2.0[c]	7	8	5	6	3	7
Smooth brome	1.5	2–3[c]	8	10	6	8	5	7
Rye or wheat cover	—	0.5–1	—	—	10	10	7	8+
Red clover	2.0	2.0	6	8	5	7	7	8+
+ 1.0 pt 2,4-D	1.5	2.0	9	10	8	9	8	9
+ 0.5 pt Banvel	1.0	1.0	10	10	9	10	8	9
Alfalfa	2.0	2.0	6	8	4	6	3	4
+ 1.0 pt 2,4-D	1.5	1.5	8	9	7	8	7	8
+ 0.5 pt Banvel	1.0	1.0	9	10	8	9	8	9
Dandelion	2.0	2.0	8	9	5	7	4	7
+ 1.0 pt 2,4-D	1.0	1.0	9	10	9	9	8	8

10 = excellent, 9 = very good, 8 = good, 7 = fair, 6 = poor, 5 and below = unacceptable, + = control at the higher end of the range. Boldface indicates acceptable control.

[a] Roundup low-rate technology = 3-10 gal/acre water + 0.5% nonionic surfactant (NIS). Can add ammonium sulfate (AMS) at 17 lb/100 gal. *Do not add residual herbicides or use liquid fertilizer carrier at these rates.*

[b] triazine = atrazine (preferred), Bladex, or Extrazine.

[c] Can possibly reduce spring Roundup rate if planted to corn and atrazine is used as a sequential treatment.

CRP land. **Roundup** is the best herbicide for "sod grass" control. *Fall application is better than spring.* Active regrowth should be 6 to 8 inches before fall application. Mowing the sod in late summer will allow adequate fall regrowth for timely fall application. Spring applications must be delayed to obtain 6 to 10 inches of new growth for effective control. *In the spring,* **Gramoxone Extra + atrazine** is about as effective as Roundup in controlling several grass species. Roundup preplant followed with atrazine at corn planting may allow reduced rates of Roundup. Corn allows the preplant or postemergence use of **2,4-D or Banvel** to control legume sods. *Thus, corn is a better crop choice than soybeans* when attempting to control grass or legume sods.

Perennial legume sods must have 6 to 8 inches of new growth for effective control. *Do not take a spring cutting before controlling legumes,* as it delays corn planting. Corn will better utilize legume nitrogen and allows preplant or postemergence use of 2,4-D or Banvel. Banvel or Marksman controls alfalfa better than 2,4-D; 2,4-D controls clover better than alfalfa. Roundup alone can be used for alfalfa or clover control, but adding 2,4-D or Banvel will improve alfalfa or clover control plus allow a lower rate of Roundup. Clover sods may be controlled by atrazine or Extrazine II.

Gramoxone Extra (paraquat) can be used to control existing vegetation before planting. Gramoxone Extra **2.5S** is used at 1.5 to 3 pints per acre. It should be applied with a nonionic surfactant or crop oil concentrate in at least 20 gallons of spray per acre. The addition of a photosynthetic inhibitor herbicide such as atrazine can improve control of smartweeds, giant ragweed, and marestail (horseweed). *Gramoxone Extra is a restricted-use pesticide.*

Roundup (glyphosate) can be used at 1 to 8 pints per acre to control existing vegetation prior to planting. Roundup at the higher rates can translocate to the roots to control some perennials. Spray volume per acre should be 10 to 40 gallons. Small annual weeds can be controlled with 0.75 to 1 pint of Roundup in 5 to 10 gallons of water per acre plus 0.5 percent nonionic surfactant. Micro-Tech or Bullet should not be mixed with Roundup unless ammonium sulfate is added at 17 pounds per 100 gallons of water. The ammonium sulfate should be mixed with water first and then the Micro-Tech or Bullet added before adding Roundup.

Bronco (glyphosate plus alachlor) contains the equivalent of 2.6 quarts of Lasso EC and 1.4 quarts of Roundup per gallon. Bronco is used at 6 to 10 pints per acre and applied in 10 to 30 gallons of water. Application can also be made in UAN solutions if annual weeds are less than 6 inches tall. *Bronco is a restricted-use pesticide.*

Banvel (dicamba) may be used in the fall or spring before planting corn or only in the fall before planting soybeans. Banvel can control annual and some perennial broadleaf plants, including clovers and alfalfa. A combination of Banvel plus 2,4-D can often control more weeds at lower cost.

2,4-D can be used in the fall or spring before planting corn or before no-till soybeans to control broadleaf weeds. *See current 2,4-D label.*

Herbicides for corn

Herbicides mentioned in this section are registered for use on field corn. Most are also registered for silage corn. See Table 15.05 for registered combinations. Herbicide suggestions for sweet corn and popcorn may be found in Chapter 10, "Weed Control for Commercial Vegetable Crops" of the *1995 Illinois Agricultural Pest Management Handbook.* Growers producing hybrid seed corn should check with the contracting company or the producer of inbred seed about tolerance of the parent lines. Rates for preplant and preemergence herbicides to use on several typical Illinois soils are given in Table 15.06. See Tables 15.07 and 15.09 for weeds controlled by the herbicides used in corn.

Early preplant not incorporated (corn)

Early preplant applications in no-till corn programs are used to minimize existing vegetation problems and reduce the need for a burndown herbicide at planting. Atrazine, Bladex, and Extrazine II have both foliar and soil activity, so they may control small annual weeds (Table 15.03) prior to planting corn, especially if a crop oil concentrate is added to the spray mix.

Atrazine, Bicep, Bullet, Cycle, Dual, Frontier, Guardsman, Harness Xtra, or Micro-Tech can be applied within 30 days of planting as a single full-rate application or within 45 days if the application is split before and at planting. **Broadstrike + Dual, Surpass, or Surpass 100** can be applied within 30 days and **Bladex or Extrazine II** within 15 to 30 days of planting corn. **Pursuit, Pursuit Plus, or Contour** can be applied within 45 days of planting imidazolinone-tolerant or -resistant (IMI) corn. These herbicides are discussed further in the upcoming sections on soil-applied herbicides.

Gramoxone Extra, Roundup, 2,4-D ester, Banvel, Clarity, or Marksman should be added to the spray mix if weeds are over 2 to 3 inches tall (check label recommendations for individual species). Gramoxone Extra and Roundup are discussed in the earlier "Conservation Tillage and Weed Control" section of this chapter. Banvel, Clarity, or Marksman will control clover or alfalfa if applied after 6 to 8 inches of new growth. Adding 2,4-D will improve control of dandelions. See Table 15.03 for weeds controlled by these herbicides.

Soil-applied "grass" herbicides (corn)

The common soil-applied grass herbicides are thiocarbamates and acetamides, which are meristematic inhibitors. The triazines Bladex, atrazine, and Extrazine II are sometimes used for grass plus broadleaf weed control.

Sutan+ (butylate) and Eradicane (EPTC) are thiocarbamates that require incorporation. Sprays need to

Table 15.05. Registered Herbicide Combinations for Preplant Incorporated, Preemergence, or Early Postemergence Application in Corn

	Atrazine	Bladex or Extrazine II	Banvel, Clarity, or Marksman	Pursuit[a]
Used alone	1,2,3	1,2,3	2,3	1,2,3
Eradicane	1	1	—	1
Sutan+	1	1	—	1
Dual, Dual II	1,2,3	1,2	2,3	1,2,3
Frontier	1,2,3	1,2	2,3	1,2,3
Micro-Tech, Lasso	1,2,3	1,2	2,3	1,2,3
Harness, Surpass	1,2	1[b],2[b]	2[c]	—
Prowl	2,3	2,3	2,3	2,3

1 = preplant incorporated; 2 = preemergence; 3 = early postemergence; — = not registered.
[a] Use Pursuit only with tolerant or resistant corn hybrids.
[b] Bladex, not Extrazine.
[c] Not Clarity.

Table 15.06. Corn Herbicides: Preplant or Preemergence Rates per Acre

Herbicide (unit)	1% OM sandy loam[a]	1–2% OM silt loam[b]	3–4% OM silty clay loam[c]	5–6% OM silty clay[c]
Atrazine 4L (pt)	4.0	4.0	4.0	4.0
Atrazine 90DF (lb)	2.2	2.2	2.2	2.2
Banvel 4S (pt)	No[d]	No[d]	1.0	1.0
Bicep 6L (pt)	3.0	3.6	4.8	6.0
Bicep II 5.9L (pt)	3.0	3.6	4.8	6.0
Bicep Lite 5L (pt)	3.0	3.6	4.8	6.0
Bladex 4L (pt)	2.5[e]	4–5	7–8	9.5
Bladex 90DF (lb)	1.3[e]	2.5	4.4	5.3
Broadstrike + Dual (pt)	1.75	2.25	2.5	2.5
Broadstrike Pre/PPI (lb)	0.20	0.25	0.30	0.30
Bullet 4L (pt)	5.0	6.0	8.0	9.0
Cycle 4L (pt)	5.0[e]	6–7	8–9	9–10
Dual 8E (pt)	1.5	2.0	2.5	3.0
Dual II 7.9E (pt)	1.5	2.0	2.5	3.0
Dual 25G (lb)	6.0	8.0	10.0	12.0
Eradicane 6.7E (pt)	4.75	4.75[f]	4.75[f]	4.75[f]
Extrazine II 4L (pt)	2.5	4–5	8–9	10.5
Extrazine II 90DF (lb)	1.4	2.5	5.0	5.8
Frontier 7.5E (fl oz)	14.0	16.0	22.0	25.0
Guardsman 5L (pt)	2.5	3.0	4.5	5.0
Harness 7E (pt)	1.5	2.0	2.5	2.75
Harness Xtra 6.1L (pt)	3.6	4.6	4.6	4.6
Lasso 4E (pt)	4.0	4.5	5.5	6.5
Lasso II 15G (lb)	16.0	20.0	22.0	26.0
Marksman 3.3L (pt)	No[d]	No[d]	3.5	3.5
Micro-Tech 4ME (pt)	4.0	4.5	5.5	6.5
Partner 65DF (lb)	3.0	3.5	4.0	5.0
Princep 4L (pt)	4.0	4.0	4.8	6.0
Princep 90DF (lb)	2.2	2.6	3.3	4.4
Prowl 3.3E (pt)	2.0	3.0	4.0	4.8
Pursuit Plus (pt)[g]	2.5	2.5	2.5	2.5
Surpass 6.4E (pt)	1.5	2.0	2.5	3.0
Surpass 100 5L (pt)	3.2	4.0	5.2	6.6
Sutan+ 6.7E (pt)	4.75[f]	4.75[f]	4.75[f]	4.75[f]

OM = percent organic matter in the soil.
[a] Characteristic of most sandy soils in Illinois.
[b] Characteristic of many Illinois soils south of Interstate 70.
[c] Characteristic of many "prairie soils" in northern Illinois.
[d] If planted to no-till corn, can use 0.5 pt Banvel or 2 pt Marksman.
[e] May cause crop injury on this soil.
[f] Use a higher rate (up to 7.33 pints) for heavy infestations and certain weeds.
[g] Use only on imidazolinone-tolerant or -resistant (IMI) corn hybrids.

be incorporated into the soil within 4 hours to minimize surface loss, but if impregnated on dry fertilizer, incorporation should be the day of application. Whenever possible, application and incorporation should be done in the same operation. Apply within 2 weeks of expected planting date. Sutan+ and Eradicane control annual grasses (Table 15.07) plus a few broadleaf weeds. The rate is 4.75 to 7.33 pints per acre, with the higher rate used for heavy weed infestations or to suppress problem weeds such as sandbur, yellow nutsedge, and shattercane. Tank-mixes with atrazine, Bladex, or Extrazine II (Table 15.05) will improve broadleaf control.

Acetamide herbicides for corn are acetochlor, alachlor, dimethenamid, and metolachlor, which control annual grasses (Table 15.07) and some small-seeded broadleaf weeds. To improve broadleaf weed control, they are formulated as premixes with atrazine or can be tank-mixed with atrazine, Bladex, or Extrazine II. If herbicides are used at planting and adequate rainfall does not occur soon, consider rotary hoeing or cultivation if the cropping plan and planting pattern allow.

Dual or Dual II (metolachlor) may be applied and incorporated within 14 days of planting or applied after planting corn. Rates per acre are 1.5 to 4 pints of Dual or Dual II or 6 to 16 pounds of Dual 25G. **Bicep 6L and Bicep Lite 5L,** 5:4 and 2:1 premixes, respectively, of metolachlor (Dual) and atrazine, are used at 3 to 6 pints per acre. **Bicep II and Dual II** contain a safening agent to minimize corn injury. *Bicep, Bicep II, and Bicep Lite are restricted-use pesticides.*

Lasso, Micro-Tech, or Partner (alachlor) may be applied and incorporated within 14 days of planting or applied after planting corn. Use 4 to 8 pints per acre of Lasso 4E or Micro-Tech 4E or equivalent rates of Lasso II 15G or Partner 65WDG. **Cropstar 20G** is intended for mixing and applying with dry fertilizer. **Bullet 4L and Lariat 4L** are 5:3 premixes of alachlor and atrazine used at 5 to 10.5 pints per acre. Bullet, Micro-Tech, and Partner contain encapsulated alachlor to increase persistence and reduce corn injury. *All products containing alachlor are restricted-use pesticides.*

Frontier 7.5E (dimethenamid) may be applied at 13 to 25 fluid ounces per acre within 2 weeks of planting and incorporated or applied after planting

Table 15.07. **Corn Herbicides: Grass and Nutsedge Control Ratings**

Herbicide	GFT	YFT	FLP	BYG	CBG	WCG	SBR	SHC	JHG	QKG	WSM	YNS	Corn Response[a]
Soil-Applied													
Dual II	9	9	8+	8+	9	7	7	5	0	0	0	8+	1
Frontier	9	9	8	8+	8	7	7	5	0	0	0	8	1+
Harness, Surpass	9	9	8+	8+	9	8	7	5	0	0	0	8	1+
Micro-Tech	9	9	8	8+	9	7	7	5	0	0	0	8	1+
Eradicane	9	9	9	9	9	8	9	8	7	6	3	8	1+
Sutan+	9	9	9	9	9	8	9	7	6	6	5	8	1
Prowl	8	8	8	8	9	8	8	7	2	0	0	0	2
Pursuit[b]	7	6	7	6	7	6	5	7	3	0	0	4	1
Atrazine	7	7	3	8	5	4	7	2	0	6	3	5	0
Bladex	8	8	8	7	7	6	7	2	0	3	0	5	2
Extrazine II	8	8	8	7	7	8	7	2	0	3	2	5	2
Princep	7	7	5	8	7	4	5	4	0	4	2	2	0
Postemergence													
Accent	9	8	8	8+	5	8	8	9+	9	9	7	6	1
Beacon	7	5	7	5	5	2	6	9+	8	8	5	7	2
Pursuit[b]	8	6	7	7	7	5	6	8+	4	0	0	5	1+
Atrazine + oil	7	7	5	7	5	6	7	2	0	6	3	7	1+
Bladex	8	8	8	8	7	7	7	2	0	3	2	5	2

GFT = giant foxtail, YFT = yellow foxtail, FLP = fall panicum, BYG = barnyardgrass, CBG = crabgrass, WCG = woolly cupgrass, SBR = sandbur, SHC = shattercane, JHG = johnsongrass, QKG = quackgrass, WSM = wirestem muhly, YNS = yellow nutsedge.
In weed columns, 10 = 95 to 100% control, 9 = 85 to 95%, 8 = 75 to 85%, 7 = 65 to 75%, 6 = 55 to 65%, 5 and below = insignificant control, + = control at the higher end of the range. Boldface indicates acceptable control.
[a] Ratings in this column compare crop injury responses among listed herbicides. Zero indicates the least potential for injury response; 1 indicates a tolerable response; 2 indicates the highest tolerable injury level.
[b] Use only on imidazolinone-tolerant or -resistant (IMI) corn hybrids.

corn. **Guardsman 5L,** a 7:8 premix of dimethenamid and atrazine, is used at 2.5 to 5 pints per acre. *Guardsman is a restricted-use pesticide.*

Atrazine plus Lasso, Micro-Tech, Dual, or Frontier or the respective premixes of Lariat, Bullet, Bicep, and Guardsman may be applied after planting until corn is 5 to 8 inches tall, but grass weeds should be less than 1.5 inches tall or not exceeding the two-leaf stage. *Do not use liquid fertilizer as the carrier after corn emergence.*

Harness 7E and Surpass 6.4E (acetochlor) may be applied within 14 days before planting and incorporated or applied after planting but before corn emergence. Use 1.25 to 3 pints of Harness or 1.5 to 3.75 pints per acre of Surpass. **Surpass 100 5L,** a 3:2 premix of acetochlor and atrazine, is used at 3.2 to 6.6 pints per acre. **Harness Xtra 6.L,** a 2.5:1 premix of acetochlor:atrazine, is used at 1.5 to 2.3 quarts per acre. This low ratio of atrazine may result in erratic control of cocklebur, annual morningglories, and velvetleaf, especially under dry weather conditions. Harness Xtra, Harness, Surpass, and Surpass 100 have crop safeners added to the formulation to minimize corn injury. *All products containing acetochlor are restricted-use pesticides.* Read the label closely for further restrictions.

Prowl 3.3E (pendimethalin) can be used preemergence-only after planting corn, *but do not incorporate.* Corn should be planted at least 1.5 inches deep. The rate is 1.8 to 4.8 pints per acre alone or 1.8 to 3.6 pints per acre in tank-mix combinations (Table 15.05). Many Prowl tank mixes can be applied early postemergence, but see the label for corn size limitations.

Soil-applied "broadleaf" herbicides (corn)

AAtrex or Atrazine (atrazine) or Princep (simazine) is often incorporated before planting because of low solubility. Atrazine is used alone at 4 pints of 4L or 2.2 pounds of 90DF (2.0 pounds active ingredient, or a.i.) per acre except on highly erodible land (HEL) with less than 30 percent residue cover, where 1.6 pounds a.i./acre is the maximum allowed. A 1:1 mixture of simazine and atrazine is often used in southern Illinois. When mixed with "grass" herbicides (Table 15.04), the atrazine rate to control broadleaf weeds is 2 to 3 pints of 4L or 1.1 to 1.8 pounds of 90DF. *All products containing atrazine are restricted-use pesticides because of the risk of groundwater and surface water contamination.*

Atrazine and simazine can persist to injure some rotational crops. The risk of carryover is greater after a cool, dry season and on soils with pH greater than 7.2. Soybeans planted the next year may show injury from atrazine carryover. If you apply atrazine after June 10, plant only corn or sorghum the next year. *Do not plant small grains, clovers, alfalfa, or vegetables in the fall or the next spring after using atrazine.*

Bladex (cyanazine) controls most annual grasses better than atrazine (Table 15.07) but is weaker on most broadleaf weeds. Bladex is less persistent than atrazine but is more likely to injure corn. **Extrazine II** is a 3:1 premix of cyanazine and atrazine. Select rates of Bladex or Extrazine II accurately on the basis of soil texture and organic matter content to reduce the possibility of corn injury (Table 15.06). Rates for soil-applied Extrazine II used alone are 1.4 to 5.8

pounds of DF or 2.5 to 10.5 pints of 4L per acre. Bladex rates are slightly lower. Bladex and Extrazine II can be used for broadleaf weed control at reduced rates with "grass" herbicides (Table 15.05). *Bladex and Extrazine II are restricted-use pesticides.*

Cycle 4L, a 1:1 premix of metolachlor (Dual) plus cyanazine (Bladex), can be applied up to 14 days prior to planting and incorporated or used preemergence after planting. The rate is 5 to 10 pints per acre. *Cycle is a restricted-use pesticide.*

Best management practices (BMP) are mandated by labels of Atrazine, Bladex, Extrazine II, Cycle, and all premixes containing atrazine to protect groundwater and surface water. *Required buffer zones (setbacks) are as follows:* No application is allowed within 66 feet of points where field surface water can enter perennial or intermittent streams and rivers (if HEL, this 66 feet must be in crops or grass, i.e., a filter strip) or within 200 feet of lakes and reservoirs. No mixing or loading is allowed within 50 feet of streams, rivers, lakes, or reservoirs.

Maximum allowable rates are lowest for highly erodible land with less than 30 percent plant residue cover (HEL < 30 percent PRC), where the maximum atrazine rate is 1.6 pounds a.i./acre soil-applied or 2.0 pounds a.i./acre postemergence, and the maximum cyanazine rate is 3.0 pounds a.i./acre (total per year, any time). On other soils, the maximum atrazine rate is 2 pounds a.i./acre and a total of 2.5 pounds a.i./year for all soils, while the maximum cyanazine rate is the label rate, but the total is not to exceed 6.5 pounds a.i./acre per year.

Premixes containing atrazine or cyanazine make calculations of total use difficult, especially if both soil-applied and postemergence premixes are used. Pounds of active ingredient of atrazine and cyanazine per gallon or pint of liquid corn herbicides are listed in Table 15.08.

For example (refer to Table 15.08), if you apply Bicep 6L at 4.8 pints (1.602 pounds a.i. atrazine) and Marksman 3.2L at 3.5 pints (0.919 pounds a.i. atrazine) per acre, you have applied a total of 2.521 pounds a.i. of atrazine per acre. This is slightly above the 2.50 pounds a.i. of atrazine allowed per year on any soil.

Broadstrike + Dual 7.67E (flumetsulam + metolachlor) may be applied at 1.75 to 2.5 pints per acre up to 14 days prior to planting and incorporated or applied after planting corn. **Broadstrike Plus Corn Pre/PPI (flumetsulam + clopyralid)** may be applied at 0.2 to 0.3 pound per acre (1.67 to 2 acres per packet) up to 30 days prior to planting and incorporated (PPI) or after planting (Pre) to field. This premix controls only broadleaf weeds, so it can be tank-mixed with appropriate "grass control" herbicides. *Observe label precautions on drift and tank cleanup, as this premix contains clopyralid, the active ingredient in Stinger.* Both Broadstrike premix labels have precautions regarding both low and high soil pH as well as soil insecticide use, so consult the label before applying them. *Be sure soil insecticides are applied in a T-band and not placed in-furrow.*

Pursuit (imazethapyr) can be used preplant incorporated or preemergence only on Pursuit-resistant or -tolerant (IMI) corn hybrids. **Pursuit Plus (imazethapyr + pendimethalin)** can be used preplant (not incorporated) or preemergence, **Contour (imazethapyr + atrazine)** can be applied preplant incorporated or preemergence. *Do not tank-mix Pursuit with Accent or Beacon. Do not apply Pursuit to IT (tolerant) corn hybrids if Counter 15G was applied in-furrow at planting.*

Banvel or Clarity (dicamba) and Marksman (dicamba + atrazine) can be applied preemergence-only on medium- or fine-textured soils containing at least 2 percent organic matter where the rate is 1 pint of Banvel or Clarity or 3.5 pints of Marksman per acre. On other soils, *only if the corn is planted no-till,* use 0.5 pint of Banvel or Clarity or 2 pints per acre of Marksman. Banvel, Clarity, or Marksman can be tank-mixed with preemergence "grass" herbicides (Table 15.05), but do not incorporate. *Marksman is a restricted-use pesticide.*

Postemergence herbicides (corn)

Bicep, Bullet, Guardsman, and Lariat as well as some preemergence tank mixes containing atrazine

Table 15.08. Corn Herbicides Containing Atrazine and Cyanazine

	Lb a.i. atrazine		Lb a.i. cyanazine	
Premix and form	Per gal	Per pt	Per gal	Per pt
AAtrex or Atrazine 4L	4.00	0.500	—	—
Bicep 6L or Bicep II 5.9L	2.67	0.333	—	—
Bicep Lite 5L	1.67	0.209	—	—
Bladex 4L	—	—	4.00	0.500
Buctril + atrazine 3L	2.00	0.250	—	—
Bullet or Lariat 4L	1.50	0.188	—	—
Contour 3.38L	3.00	0.375	—	—
Cycle 4L	—	—	2.00	0.250
Extrazine II 4L	1.00	0.125	3.00	0.375
Guardsman 5L	2.67	0.333	—	—
Harness Xtra 6.1L	1.74	0.217	—	—
Laddok 3.3 L	1.67	0.209	—	—
Laddok S-12	5.00	0.625	—	—
Marksman 3.2 L	2.10	0.263	—	—
Surpass 100 5L	2.00	0.250	—	—

(Table 15.05) may also be applied early postemergence to corn. Most require the grass weeds to be less than 1.5 to 2 inches tall for effective control. *Do not use a liquid fertilizer carrier (although some are used as adjuvants) when applying these premixes postemergence.*

Some postemergence herbicides control certain grass weeds (Table 15.07) while others control primarily broadleaf weeds (Table 15.09). Several postemergence herbicide tank mixes are registered (Table 15.10). Many postemergence corn herbicides require the use of an adjuvant to improve activity. Table 15.11 lists labeled adjuvants, minimum time between applications and rainfall for maximum herbicide activity, and required reentry intervals.

Postemergence grass control (corn)

Accent, Beacon, Pursuit, Atrazine, Bladex, or Extrazine II can be used to control some grass weeds (Table 15.07). Atrazine, Bladex, or Extrazine II must be applied before grass weeds are over 1.5 inches tall. These herbicides also control many broadleaf weeds (Table 15.09).

Accent or Beacon is used postemergence for shattercane and johnsongrass control in field corn. Accent provides better control of giant foxtail and fall panicum (Table 15.07), but Beacon controls more broadleaf weeds than Accent (Table 15.09).

Accent and Beacon labels both carry restrictions regarding organophosphate insecticide use. Unless an IR corn hybrid is planted, do not apply Beacon if Counter 15G or Counter 20CR has been applied, and do not apply Accent if Counter 15G was used or if Counter 20CR was applied in-furrow at planting. If Counter 20CR was applied as a T-band, temporary injury may occur after Accent application on soils with greater than 4.0 percent organic matter, but unacceptable injury may occur on soils with less than 4 percent organic matter. If Thimet, Dyfonate, or Lorsban is used at planting, temporary corn injury may occur after Accent or Beacon application. Do not apply a foliar organophosphate insecticide within 10 days before or

Table 15.09. Corn Herbicides: Broadleaf Weed Control Ratings

Herbicide	PGW	LBQ	SMW	VLV	AMG	CCB	JMW	CRW	GRW	BCC	BNS	KCH	SFR	PSD	Corn response[a]
Soil-Applied[b]															
Atrazine	9	9	10	7	8	9	10	9	8	7	9	9	8	9	0
Bladex	6	9	9	7	8	8	8	9	7	5	8	8	7	8	2
Princep	9	9	9	7	8	8	9	9	7	6	9	9	8	9	0
Marksman	9	8	9	7+	8	8	8	9	8	6	8	8	8	7	2
Broadstrike + Dual	9	9	8+	8	5	7	8	8	6	5	8	9	8+	7	1+
Broadstrike Pre/PPI	9	9	8+	8	6	8	8	8	6	5	8	9	9	7	1+
Pursuit[c]	9	8	9	8	6	7	7	6	6	6	9	8	8	8	1
Postemergence[b]															
Atrazine	10	9	10	8	9	9	9	9	8	7	9	9	9	9	1
Bladex	6	9	9	7	7	8	8	9	7	5	9	8	7	7	2
Accent	8	5	8	5	6	5	8	3	3	7	0	6	5	2	1
Beacon	8	5	7	7	6	7	8	9	9	8	8	9	9	7	2
Pursuit[c]	9	6	9	8+	7	8+	7	6	7	5	9	8	8	6	1+
Buctril	7+	9	8+	8	8	9	9	9	7	7	9	8	8	5	2
Buctril + Atrazine	10	10	10	9	9	9	10	9	8+	8	10	9	9	9	2
Laddok	9	9	10	9	8	9	10	9	8	6	9	8	10	7	1
Tough	9	9	7	6	4	8+	8+	6	7	6	9	9	8	5	1
Marksman	10	10	10	9	9	9	10	9	9	8	10	9	9	9	1+
Banvel or Clarity	9	9	10	7	9	9	9	9	9	7	9	8	8	7	1+
2,4-D	9	9	6	8	9	9	7	9	9	3	7	7	8	8	2+
Stinger	3	3	7	3	3	9	8	9	9	6	7	3	8	3	1

PGW = pigweeds, LBQ = lambsquarters, SMW = smartweeds, VLV = velvetleaf, AMG = annual morningglories, CCB = cocklebur, JMW = jimsonweed, CRW = common ragweed, GRW = giant ragweed, BCC = burcucumber, BNS = eastern black nightshade, KCH = kochia, SFR = wild sunflower, PSD = prickly sida. In weed columns, 10 = 95 to 100% control, 9 = 85 to 95%, 8 = 75 to 85%, 7 = 65 to 75%, 6 = 55 to 65%, 5 and below = insignificant control, + = control at the higher end of the range. Boldface indicates acceptable control.

[a] Ratings in this column compare crop injury responses among listed herbicides. Zero indicates the least potential for injury response; 1 indicates a tolerable response; 2 indicates the highest tolerable injury level.

[b] These herbicides may also control grasses. See Table 7.

[c] Use only on imidazolinone-tolerant or -resistant (IMI) corn hybrids.

For herbicide ratings for tank mixes or premixes, see the component parts:

Premix	Grass	Broadleaf 1	Broadleaf 2
Bicep	Dual	atrazine	
Bullet	Micro-Tech	atrazine	
Cycle	Dual	Bladex	
Extrazine II	Bladex	atrazine	
Guardsman	Frontier	atrazine	
Harness Xtra	Harness	atrazine	
Surpass 100	Surpass	atrazine	
Broadstrike + Dual	Dual	Broadstrike	
Buctril + atrazine		Buctril	atrazine
Contour		Pursuit	atrazine
Laddok		Basagran	atrazine
Marksman		Banvel	atrazine
Resolve		Pursuit	Banvel

Table 15.10. Postemergence Herbicide Tank Mixes for Corn

Herbicide	Buctril, Buctril Gel	Basagran	Laddok	Banvel, Clarity	Marksman	2,4-D	Atrazine
Accent	X	—	—	X	X	—	X
Atrazine	X	X	X	X	X	—	—
Beacon	X	—	—	X	X	X	X
Bladex	—	—	X	X	X	—	X
Pursuit	X	—	—	X	X	—	X
2,4-D	X	—	X	X	—	—	—

X = registered; — = not registered.

Table 15.11. Corn Postemergence Herbicides: Adjuvants, Rainfastness, Reentry Interval, and Timing

Herbicide	Adjuvants and nitrogen	Rain-free period (hr)	Reentry interval (hr)	Apply before corn	Use drop nozzles
2,4-D amine	None	6–8	48	Tassel	If > 8″
2,4-D ester	None	1–2	12	Tassel	If > 8″
Accent	POC, VOC, or NIS[a] plus UAN or AMS	4	12	36″	From 24″ to 36″
Atrazine	POC or VOC	1–2	12	12″	
Banvel	NIS, UAN, or AMS if drouthy[b]	4	24	36″[c]	To reduce drift
Basagran	POC or VOC plus UAN or AMS	8[d]	12	None	
Beacon	POC, VOC, or NIS[a] plus UAN or AMS	4	12	Tassel	If > 20″
Bladex 4L	None	1–2	12	5-leaf	
Bladex DF	VOC or NIS only if drouthy[b]	1–2	12	5-leaf	
Buctril	POC,[e] VOC,[e] or NIS[e]	1	12	Tassel	
Buctril + Atrazine	POC,[e] VOC,[e] or NIS[e]	1	12	12″	
Clarity	POC,[b,f] VOC,[b,f] or NIS[b] if drouthy plus UAN	4	12	8″; 5″ w/oil	
Extrazine II 4L	None	1–2	12	5-leaf	
Extrazine DF	VOC[b] or NIS[b] only if drouthy	1–2	12	5-leaf	
Gramoxone Extra	POS, VOC, or NIS	0.5	48	Tassel	
Laddok	POC or VOC plus UAN or AMS	8[d]	12	12″	
Marksman	POC,[b,f] VOC,[b,f] or NIS[b] plus UAN or AMS[b]	4	48	5-leaf or 8″	
Pursuit[h]	POC, VOC, or NIS plus UAN or AMS	1	12	45-day PHI	
Roundup[g]	NIS plus UAN or AMS	6	12	Tassel	
Stinger	None	6–8	48	24″	
Tough	None	1–2	12	68-day PHI	

POC = petroleum oil concentrate, VOC = vegetable oil concentrate, NIS = nonionic surfactant, UAN = urea-ammonium nitrate (28-0-0), AMS = ammonium sulfate, PHI = preharvest interval.
[a] Use NIS only when Accent or Beacon is mixed with anything except atrazine.
[b] Use especially if drouthy conditions exist at application.
[c] Up to 24 in. if nearby soybeans are over 10 in. or are blooming.
[d] Current label: "Rain soon after application may decrease effectiveness."
[e] Allowed if injury is acceptable.
[f] Use of oils (penetrants) may cause injury if corn is > 5 in. tall (Clarity label).
[g] Use only as a spot treatment and not as an overall application.
[h] Use on imidazolinone-resistant or -tolerant corn hybrids only.

5 days after Beacon application or 7 days before or 3 days after Accent application.

Accent 75DF (nicosulfuron) can be applied over the top of corn up to 24 inches tall (freestanding) or with 6 visible leaf collars, whichever is most restrictive. Apply with drop nozzles on corn 24 to 36 inches tall. Do not apply after corn is 36 inches tall or exhibits 10 leaf collars. Use ⅔ ounce per acre (one SP packet per 4 acres) in a minimum of 10 gallons of water for ground application. If needed, a second application can be made 14 to 28 days later. Grass height limits are 2 to 4 inches for foxtail, woolly cupgrass, or fall panicum; 4 to 12 inches for shattercane; 8 to 18 inches for rhizome johnsongrass; and 4 to 10 inches for quackgrass.

Accent can be tank-mixed with atrazine, Buctril, Buctril + atrazine, Banvel, or Marksman, but observe corn height limits for the tank-mix partner. Do not tank-mix Accent with Basagran, Bladex, Laddok, or 2,4-D, and do not apply them within 3 days after applying Accent. Use crop oil concentrate (COC) for Accent + atrazine, but use a nonionic surfactant (NIS) with the other tank-mix partners. Green and yellow foxtail control may be antagonized by tank mixes unless an ammonium fertilizer adjuvant is added. The use of COC plus an ammonium fertilizer adjuvant is recommended for controlling woolly cupgrass.

Beacon 75DF (primisulfuron) is applied to 4- to 20-inch corn at 0.76 ounce per acre, or a 1.52-ounce packet covers 2 acres. Split applications (50/50 percent

or 75/25 percent) may provide better control of johnsongrass. The second application must be made before tassel emergence and be directed with drop nozzles if corn is over 20 inches tall. Grass height sizes for Beacon are 4 to 12 inches for shattercane, 8 to 16 inches for rhizome johnsongrass, 4 to 8 inches for quackgrass, and less than 2 inches for fall panicum or foxtail. Beacon also controls several broadleaf weeds (Table 15.09).

Beacon can be tank-mixed with Accent, atrazine, Banvel or Clarity, Buctril, Buctril + atrazine, Marksman, or 2,4-D. In mixtures with Accent or atrazine, an NIS or COC is used, and urea-ammonium nitrate (UAN) can also be added. Use only NIS with mixtures with Banvel, Clarity, Buctril, Buctril + atrazine, Marksman, or 2,4-D. Observe corn size limitations for the tank-mix partner. Beacon can be used at half rate alone or with atrazine, Banvel, Buctril, Clarity, or 2,4-D to control several broadleaf weeds. Mixtures with 2,4-D, Banvel, or Clarity will suppress small pokeweed, poison ivy, and hemp dogbane. Beacon + Accent, each at half rates, will control several annual grass and broadleaf weeds.

Pursuit (imazethapyr) can be used postemergence on IMI (imidazolinone-tolerant or -resistant) corn hybrids at 4 ounces of 2S or 1.4 ounces of 70DG per acre. Apply before giant foxtail exceeds 6 inches and before most other weeds exceed 3 inches. Add either COC or NIS plus a fertilizer adjuvant (see label). **Contour (imazethapyr + atrazine)** is used at 1.33 pints per acre. **Resolve CP** is a co-pack of Pursuit and Banvel for postemergence use. Pursuit can be tank-mixed with Atrazine, Basagran, Buctril, Banvel, Clarity, or Marksman, but tank-mixing may antagonize grass control with Pursuit. Do not use COC in tank mixes with Buctril, Banvel, Clarity, or Marksman. *Do not tank-mix Pursuit with Accent or Beacon. Do not apply Pursuit to IT corn hybrids if Counter 15G was applied in-furrow at planting.*

Atrazine must be applied before corn is 12 inches tall. Use 2.2 pounds 90DF or 4 pints 4L plus 1 quart COC per acre to control annual grass weeds less than 1.5 inches tall. Many annual broadleaf weeds up to 4 inches tall are controlled with 1.3 pounds 90DF or 2.4 pints 4L plus 1 quart of COC per acre. *Do not apply more than a total of 2.5 pounds of atrazine (a.i.) per acre per year.*

Atrazine plus COC may injure corn that has been under stress from prolonged cold, wet weather or other factors. *Do not add 2,4-D with atrazine plus COC.* Mix the atrazine with water first and then add the COC. If atrazine is applied after June 10, plant only corn or sorghum the next year. *Atrazine is a restricted-use pesticide.*

Bladex (cyanazine) or Extrazine II (cyanazine + atrazine) may be applied until the five-leaf stage in field corn and before grass weeds exceed 1.5 inches in height. The rate per acre is 1.1 to 2.2 pounds 90DF or 2.2 to 4 pints 4L. Use 4L formulations only under warm, dry, sunny conditions of low humidity. Do not apply Bladex or Extrazine II to corn that is stressed or growing in cold, wet weather. Under dry, arid conditions, a surfactant or vegetable oil may be added to 90DF (not 4L) formulations. Do not use petroleum-based COC or apply with liquid fertilizer. *Extrazine II and Bladex are restricted-use pesticides.*

Postemergence broadleaf control (corn)

Banvel, Clarity, Stinger, and 2,4-D are plant hormone herbicides that control broadleaf weeds in corn (see Table 15.09). Observe drift precautions with these herbicides. Buctril, Buctril + atrazine, Tough, and Laddok are contact herbicides, so good spray coverage is essential.

Banvel or Clarity (dicamba) or Marksman (dicamba + atrazine) may be applied from spike to five-leaf or 8-inch stage in corn. Use 1 pint of Banvel or Clarity or 3½ pints of Marksman per acre except on coarse-textured soils, where the rate is ½ pint of Banvel or Clarity or 2 pints of Marksman per acre. Banvel may also be applied at ½ pint per acre to corn that is 8 to 36 inches tall or 15 days before tassels emerge, whichever comes first. Use drop nozzles on corn over 8 inches tall, especially if Banvel is applied with 2,4-D, to reduce the risk of corn injury, improve spray coverage, and reduce drift. *Do not apply Banvel to corn over 24 inches tall if nearby soybeans are over 10 inches tall or have begun to bloom.* Observe all label precautions to minimize the risk of Banvel or Marksman drifting to nearby susceptible crop or ornamental plants.

The addition of a nonionic surfactant (NIS) to Clarity is allowed, and crop oil concentrate (COC) may be added up to the 5-inch stage under dry conditions. Add fluid fertilizer at 0.5 to 1 gallon per acre to improve velvetleaf control. Up to two Clarity applications may be made during the growing season, allowing at least 2 weeks between applications. Do not exceed 24 fluid ounces per treated acre.

Stinger (clopyralid) can be used on field corn up to 24 inches in height. The rate is ¼ to ½ pint per acre for ragweed, cocklebur, sunflower, Jerusalem artichoke, and jimsonweed up to the five-leaf stage, and ⅓ to ⅔ pint per acre for Canada thistle from 6- to 8-inch rosette up to the bud stage. The interval before planting soybeans is 10.5 months after application.

2,4-D amine or ester can be used from emergence to tasseling of corn. Apply with drop nozzles if corn is more than 8 inches tall. The rate is ⅓ to ½ pint of 2,4-D ester or 1 pint of 2,4-D amine per acre if the acid equivalent is 3.8 pounds per gallon. 2,4-D ester can volatilize and injure nearby susceptible plants if temperatures exceed 85°F. Spray particles of either 2,4-D ester or amine can drift and cause injury to susceptible plants.

Corn is often brittle for 1 to 2 weeks after application of 2,4-D and may be susceptible to stalk breakage from high winds or cultivation. Other symptoms of 2,4-D injury are stalk lodging, abnormal brace roots, and failure of leaves to unroll. Corn hybrids differ in

their sensitivity to 2,4-D. High humidity and temperature increase the potential for 2,4-D injury to corn.

Buctril 2EC (bromoxynil) is used at 1 pint per acre after emergence or up to 1.5 pints per acre after the four-leaf stage of corn up to tassel emergence, but while weeds are in the three- to eight-leaf stage. Larger pigweed and velvetleaf may require the higher rate or a combination with atrazine. Buctril Gel 4E is a 2.5-pint water-soluble packet equivalent to 5 pints of Buctril 2E.

Buctril + Atrazine 3L is used at 1.5 to 3 pints per acre, or Buctril can be tank-mixed with 1 to 2.4 pints atrazine 4L or 0.6 to 1.3 pounds atrazine 90DF. At the higher rate, do not apply until the four-leaf stage of corn. Do not apply to corn over 12 inches tall. NIS or COC can be added, but the potential for corn injury increases. *Buctril + Atrazine is a restricted-use pesticide.*

Laddok (bentazon + atrazine) will be available in two formulations in 1995. Use 1.33 to 2.33 pints of Laddok S-12 5L or 2 to 3.5 pints of the older Laddok 3.32L per acre until corn is 12 inches tall. Always add 1 gallon of UAN or 1 quart of COC or Dash per acre for ground application. Use the COC or Dash for suppression of Canada thistle or yellow nutsedge. A tank mix of Laddok plus 2 to 4 ounces of 2,4-D ester per acre will provide improved control of field and hedge bindweed. Use only 28 percent urea-ammonium as an adjuvant in this tank mix. *Laddok is a restricted-use pesticide.*

Tough 3.75 EC (pyridate) plus atrazine can be used in field corn at the rate of 1 pint per acre of each product. This combination can be applied up to 68 days before harvest. Optimum control occurs when the application is made to weeds with one to four true leaves.

Postemergence soil-applied herbicides (corn)

Some herbicides that are normally applied to the soil may be used postemergence in corn to back up herbicides that were applied earlier and to keep late-emerging weeds from becoming problems. Drop nozzles should be used if corn foliage prevents uniform application to the soil.

Prowl (pendimethalin) or Treflan (trifluralin) may be applied after *field corn* is 4 inches tall (for Prowl) or from the two-leaf stage (for Treflan) up to last cultivation. Prowl or Treflan plus atrazine can be tank-mixed, but do not apply after corn is 12 inches tall. Apply the herbicide and then incorporate with a sweep or rolling cultivator. Prowl may not require incorporation if rainfall occurs soon after application. These treatments are used to help control late-emerging grasses such as shattercane, wild proso millet, fall panicum, and woolly cupgrass. *Do not use Prowl in corn more than once per crop season.* Observe recropping restrictions, especially for wheat.

Dual (metolachlor) plus atrazine as a tank mix or premix (Bicep) can be used postemergence to control weeds in corn up to 12 inches tall, especially in seed corn, where late-emerging weeds become problems. See the current label for rate and timing restrictions.

Directed postemergence herbicides for emergencies (corn)

Directed (not over-the-top) sprays of Lorox, Gramoxone Extra, or Evik can be used for emergencies if weed and crop size limits are met. Early cultivation may allow for the proper height differential between the crop and weeds. Direct the spray to the base of the corn plants to minimize injury to the corn while covering the weeds as much as possible. *Adjust rates for banded application.*

Lorox (linuron) may be used in field corn at least 15 inches tall (freestanding) but before weeds are 5 inches tall. Use Lorox at 1.25 to 3 pounds 50DF per acre, depending upon the weed size and soil type. Add 1 pint of surfactant per 25 gallons of spray.

Gramoxone Extra (paraquat) may be applied after corn is 10 inches tall as a directed spray no higher than the lower 3 inches of cornstalks. Use 12.8 fluid ounces of Gramoxone Extra in a minimum of 20 gallons of water per acre. A nonionic surfactant or crop oil concentrate should be added. A tank mix with atrazine can increase broadleaf control. Observe current label precautions. *Gramoxone Extra is a restricted-use pesticide.*

Evik 80W (ametryn) may be used in field corn at least 12 inches tall but before weeds are 2 to 4 inches tall. Use 2 to 2.5 pounds of Evik 80W in a minimum of 20 gallons of water per acre. Add nonionic surfactant at 2 quarts per 100 gallons of water.

Corn preharvest treatment

Some 2,4-D labels allow preharvest use after the hard-dough to dent stages of corn to control or suppress broadleaf weeds that may interfere with harvest. Do not use the corn for forage or fodder for 7 days after treatment.

Herbicides for sorghum

Atrazine, Dual, Banvel, Bicep, 2,4-D, and Buctril are registered for use in grain or "forage" sorghums. Several other corn herbicides can also be used in grain sorghum, or milo, although the application rates may be lower. Check the labels for the relevant information.

Gramoxone Extra (paraquat) or Roundup (glyphosate) can be used to control existing vegetation before planting grain sorghum in reduced-tillage systems. **Bronco (glyphosate + alachlor)** can also be used if the seed is treated with Screen. *Gramoxone Extra and Bronco are restricted-use pesticides.*

Atrazine may be applied to medium-textured soils with more than 1 percent organic matter, but the rates are lower than for corn. Atrazine can also be applied postemergence at 4 pints 4L per acre without crop oil concentrate (COC) or at 2.4 pints per acre with COC

for broadleaf control only. Use equivalent rates of atrazine 90DF. *Atrazine is a restricted-use pesticide.*

Ramrod (propachlor) alone or with atrazine or Bladex can be used only preemergence in grain sorghum. Do not graze or feed treated forage to dairy animals.

Lasso (alachlor) or Lariat (alachlor + atrazine) can be used if grain sorghum seed is treated with Screen. Micro-Tech and Bullet are not registered for use in grain sorghum. *Lasso and Lariat are restricted-use pesticides.*

Dual (metolachlor), Bicep (metolachlor + atrazine), or Cycle (metolachlor + cyanazine) can be used if grain sorghum seed has been treated with Concep II. *Bicep and Cycle are restricted-use pesticides.*

2,4-D may be applied for broadleaf control in sorghum that is 4 to 24 inches tall. Use drop nozzles if sorghum is taller than 8 inches.

Banvel (dicamba) or Marksman (dicamba + atrazine) can be applied to grain sorghum after the two-leaf stage. Marksman can be applied at 1½ to 2 pints per acre until sorghum has five leaves or is 8 inches tall; Banvel can be applied at 0.5 pint per acre to sorghum up to 15 inches tall. Do not graze or feed treated forage to animals before the mature grain stage. *Marksman is a restricted-use pesticide.*

Laddok S-12 (bentazon + atrazine) can be used postemergence to control broadleaf weeds in grain or forage sorghum if applied before the crop is 12 inches tall. *Laddok is a restricted-use pesticide.*

Buctril (bromoxynil) applied alone can be used from the three-leaf to boot stages, whereas Buctril that has been tank-mixed or premixed with atrazine can only be applied to grain sorghum up to 12 inches in height.

Roundup (glyphosate) may be applied as a spot treatment in grain sorghum prior to heading.

Herbicides for soybeans

Soybeans may be injured by some herbicides, but if stands have not been significantly reduced, they usually outgrow early injury with little or no effect on yield. Significant yield decreases can result when injury occurs during the bloom to pod-fill stages. Excessively shallow planting can increase the risk of injury from some herbicides. Accurate rate selection for soil type is essential for herbicides containing metribuzin (Canopy, Lexone, Preview, Salute, Sencor, or Turbo) or linuron (Lorox or Lorox Plus) (Table 15.12). *Do not apply these herbicides after soybeans begin to emerge, or severe injury can result.* Always follow label instructions. Rates per acre for preplant and preemergence herbicides for typical Illinois soils are given in Table 12. See Table 15.13 for some preplant and preemergence tank-mix combinations.

Consider the kinds of weeds expected when you plan a herbicide program for soybeans. See herbicide selectivity Tables 15.14, 15.15, and 15.16 for the relative weed-control ratings for various weeds with different soybean herbicides.

Early preplant herbicides not incorporated (soybeans)

Early preplant applications of herbicides are used in no-till soybeans to minimize existing vegetation and reduce the need for a knockdown herbicide. Most broadleaf herbicides used in early preplant application have both foliar and soil activity, so they may control small annual weeds (Table 15.03), especially if a nonionic surfactant (NIS) or crop oil concentrate (COC) is added to the spray mix. However, if weeds are over 1 to 2 inches tall, add **Gramoxone Extra, Roundup, or 2,4-D** to the spray mix within label guidelines to control existing vegetation. (See the earlier section on "Conservation Tillage and Weed Control").

Dual, Frontier, Micro-Tech, Partner, Prowl, and Command can be applied early preplant for grass control. Dual, Frontier, Micro-Tech, and Partner can be applied within 30 days of planting as a single application or within 45 days if split-applied, preplant plus at planting. Prowl can be applied within 45 days of planting no-till soybeans. Command can be applied early preplant for no-till soybeans. *Applications must be made prior to field greenup and, in Illinois, before April 1 south of Interstate 80 or April 10 north of Interstate 80.*

Canopy, Lorox Plus, Preview, Pursuit, Scepter, and Sencor can be applied early preplant within 45 days prior to planting soybeans for broadleaf weed control. **Pursuit Plus and Squadron** can also be applied within 45 days prior to planting. **Sencor + Lasso or Dual** can be applied 14 days prior to planting as a single application or 30 days if split-applied, preplant plus at planting. **Turbo** is a premix of Sencor and Dual. **Broadstrike + Dual** can be applied within 30 days on most soils. Apply within 14 days prior to planting soybeans on coarse-textured soils.

Assure II, Fusion, Poast Plus, and Select applied preplant at reduced rates can control 3- to 5-inch annual grasses. Always add COC (or Dash with Poast Plus). These herbicides can be tank-mixed with 2,4-D (next paragraph) to control broadleaf weeds prior to planting soybeans.

2,4-D LV Ester can be applied prior to planting *no-till soybeans.* See Table 15.03 for weeds controlled. Apply 1 pint (3.8 pounds acid equivalent [a.e.] per gallon) per acre 7 days before or 2 pints per acre 30 days before planting soybeans. Check the label for rates of other 2,4-D formulations. To minimize potential injury, plant soybeans 1.5 to 2 inches deep, and be sure the seeds are covered with soil. *Do not use on sandy soils with less than 1 percent organic matter.* 2,4-D can be tank-mixed with most other early preplant herbicides.

Soil-applied "grass" herbicides (soybeans)

Treflan, Sonalan, and Command are soil-applied "grass" herbicides that require mechanical incorpora-

Table 15.12. Soybean Herbicides: Preplant/Preemergence Rates per Acre

Herbicide (unit)	1% OM sandy loam[a]	1–2% OM silt loam[b]	3–4% OM silty clay loam[c]	5–6% OM silty clay[c]
Broadstrike + Dual (pt)	2.00	2.25	2.50	2.50
Broadstrike + Treflan (pt)	1.50	2.00	2.25	2.25
Bronco 4L (pt)	6.0	8.0	9.0	10.0
Canopy 75DF (oz)	5.0[d]	6.0	6.5	7.0
Command 4E (pt)	1.0	1.5	2.0	2.0
Commence 5.5L (pt)	1.75	2.0	2.5	2.67
Dual 8E (pt)	1.5	2.0	2.5	3.0
Dual 25G (lb)	6.0	8.0	10.0	12.0
Freedom 3E (pt)	6.0	7.0	8.0	9.0
Frontier 7.5E (fl oz)	14.0	16.0	22.0	25.0
Lasso 4E (pt)	4.0	4.5	5.5	6.5
Lasso II 15G (lb)	16.0	20.0	22.0	26.0
Lexone 75DF (lb)	0.33[d]	0.50	0.67	0.67
Lorox 50DF (lb)	0.75[d]	1.3	2.0[e]	3.0[e]
Lorox Plus 60DF (oz)	12.0[d]	14.0	16.0	18.0[e]
Micro-Tech 4En (pt)	4.0	4.5	5.5	6.5
Partner 65DF (lb)	3.0	3.5	4.0	5.0
Passport 2.8E (pt)	2.5	2.5	2.5	2.5
Preview 75DF (oz)	6.0[d]	7.0	9.0	10.0
Prowl 3.3E (pt)	1.8	2.4	3.0	3.6
Pursuit 2S (pt)	0.25	0.25	0.25	0.25
Pursuit 70DG (oz)	1.4	1.4	1.4	1.4
Pursuit Plus 2.9E (pt)	2.5	2.5	2.5	2.5
Salute 4L (pt)	1.5[d]	2.25	2.5	3.0
Scepter 1.5S (pt)	0.67	0.67	0.67[f]	0.67[f]
Scepter 70DG (oz)	2.8	2.8	2.8[f]	2.8[f]
Sencor 4L (pt)	0.5[d]	0.75	1.00	1.25
Sencor 75DF (lb)	0.33[d]	0.50	0.67	0.83
Sonalan 3E (pt)	1.5	2.0	2.5	3.0
Squadron 2.3E (pt)	3.0	3.0	3.0[f]	3.0[f]
Treflan 4E (pt)	1.0	1.5	2.0	2.0
Tri-Scept 3E (pt)	2.3	2.3	2.3[f]	2.3[f]
Turbo 8E (pt)	1.5[d]	2.0	2.5	3.0

OM = percent organic matter in the soil.
[a] Characteristic of most sandy soils in Illinois.
[b] Characteristic of many Illinois soils south of Interstate 70.
[c] Characteristic of "prairie soils" in northern Illinois.
[d] May cause excess crop injury on these soils.
[e] May not be suitable on these soils.
[f] Carryover injury to corn may occur on these soils unless imidazolinone-resistant or -tolerant corn hybrids are planted.

Table 15.13. Herbicide Tank Mixes for Preplant-Incorporated or Preemergence Use in Soybeans

Herbicide	Sencor or Lexone	Canopy or Preview	Scepter	Pursuit	Command	Lorox	Lorox Plus
Preplant-Incorporated							
Command	1	1	1	—	—	—	—
Commence	1	1	1	—	—	—	—
Salute	—	1	1	1	1	—	—
Sonalan	1	1	—	—	1	—	1
Trifluralin	1	1	1	1	1	—	1
Preplant-Incorporated or Preemergence							
Dual	1,2	1,2	1,2	1,2	1	2	1,2
Freedom	1,2	1,2	1,2	—	1	2	1,2
Frontier	1,2	1,2	1,2	1,2	1	2	1,2
Micro-Tech	1,2	1,2	1,2	1,2	1	2	1,2
Prowl	1,2	1,2	1,2	1,2	1	2	1,2

1 = preplant incorporated; 2 = preemergence; — = not registered.

tion, whereas Dual, Frontier, Lasso, Micro-Tech, and Prowl can be used preplant-incorporated or preemergence. *Do not apply Prowl preemergence north of Interstate 80.* Incorporation improves herbicide performance if rainfall is limited. For more information, see the earlier section titled "Herbicide Incorporation" and Tables 15.13 and 15.14 for the weeds controlled.

Treflan, Sonalan, and Prowl are dinitroaniline (DNA) herbicides that control annual grasses, pigweeds, and lambsquarters. Control of additional broadleaf weeds requires combinations or sequential treatments with other herbicides.

Soybeans are sometimes injured by DNA herbicides. Symptoms are stunting, swollen hypocotyls, and short,

Table 15.14. Soybean Herbicides: Grass and Nutsedge Control Ratings

Herbicide	GFT	YFT	FLP	BYG	CBG	WCG	SBR	SHC	VCN	VCL	JHG	QKG	WSM	YNS	Soybean response[a]
Soil-Applied[b]															
Dual	9	9	8+	8+	9	7	7	5	0	3	0	0	0	8+	1
Frontier	9	9	8+	8+	8	7	7	5	0	3	0	0	0	8	1
Micro-Tech	9	9	8	8+	9	7	7	5	0	3	0	0	0	8	1
Command	9	9	9	9	9	8	8	6+	5	9	2	0	0	3	1
Prowl	9	9	9	9	9	9	8	8	4	6	3	0	0	0	1+
Sonalan	9	9	9	9	8	8	8	7	4	6	2	0	0	0	2
Trifluralin	9	9	9	9	9	9	9	8	5	6	3	0	0	0	1+
Postemergence															
Assure II	9+	7	9	8+	8+	8	9	10	10	9	9	9	9	0	0
Fusilade DX	8	8	8	8+	8	9	9	10	10	9	9	9	9	0	0
Fusion	9	8+	9	8+	8+	9	9	10	10	9	8	8+	9	0	0
Poast Plus	9+	9	9	9	8	9	7	8	8	7	7	7+	8	0	0
Select	9+	9	9	9	8	9	8	9	9	8	8	8	8	0	0
Pursuit[b]	8	6	7	8	7	5	6	8+	6	3	4	0	0	5	1

Annuals: GFT = giant foxtail, YFT = yellow foxtail, FLP = fall panicum, BYG = barnyardgrass, CBG = crabgrass, WCG = woolly cupgrass, SBR = sandbur, SHC = shattercane, VCN = volunteer corn, VCL = volunteer cereals (wheat, oats, rye). *Perennials:* JHG = johnsongrass, QKG = quackgrass, WSM = wirestem muhly, YNS = yellow nutsedge. In the weed columns, 10 = 95 to 100% control, 9 = 85 to 95%, 8 = 75 to 85%, 7 = 65 to 75%, 6 = 55 to 65%, 5 and below = insignificant control, + = control at the higher end of the range. Boldface indicates acceptable control.

[a] Ratings in this column compare crop injury responses among listed herbicides. Zero indicates the least potential for injury response; 1 indicates a tolerable response; 2 indicates the highest tolerable injury level.

[b] These herbicides may also control broadleaf weeds. See Table 15.

Table 15.15. Soybean Soil-Applied Herbicides: Broadleaf Control Ratings

Herbicide	PGW	LBQ	SMW	VLV	AMG	CCB	JMW	CRW	GRW	BCC	BNS	KCH	SFR	PSD	Soybean response[a]
Soil-Applied "Grass"															
Dual	8	6	4	0	0	0	4	5	2	0	7+	5	0	0	1
Frontier	9	6	5	0	0	0	5	5	2	0	7+	6	0	0	1
Micro-Tech	9	7	5	0	0	0	5	6	2	0	7+	6	0	0	1
Prowl	9	9	4	4	3	0	2	2	0	0	0	8	0	0	1
Sonalan	9	8	4	3	3	0	2	2	0	0	6	8	0	0	2
Trifluralin	9	9	4	2	3	0	2	2	0	0	0	8	0	0	1
Soil-Applied "Broadleaf"															
Command	5	9	8	9+	0	6	8	7	5	0	6	8	4	8	1
Sencor/Lexone	9	9	9	8	3	6	7	8	5	2	3	9	7	8	2
Lorox	9	9	8	6	4	6	5	8	5	2	5	8	6	6	2
Lorox Plus	9	9	9	7	6	8	7	9	7	6	5	8	7	7	2
Canopy	9	9	9	9	7	9	9	9	8	7+	5	8	8	9	2
Preview	9	9	9	9	6	8	9	9	7	6	5	8	8	8	2
Broadstrike	9	9	8+	8	7	7+	7+	7+	5	5	8	8	8	7	1
Pursuit	9	8	9	8	6	7	7	7	6	6	8	8	8	8	1
Scepter	9	9	9	7	7	9	8	9	8	7+	8	8	9	8	1

PGW = pigweeds, LBQ = lambsquarters, SMW = smartweeds, VLV = velvetleaf, AMG = annual morningglories, CCB = cocklebur, JMW = jimsonweed, CRW = common ragweed, GRW = giant ragweed, BCC = burcucumber, KCH = kochia, BNS = eastern black nightshade, SFR = wild sunflower, PSD = prickly sida. In the weed columns, 10 = 95 to 100% control, 9 = 85 to 95%, 8 = 75 to 85%, 7 = 65 to 75%, 6 = 55 to 65%, 5 and below = insignificant control, + = control at the higher end of the range. Boldface indicates acceptable control.

[a] Ratings in this column compare crop injury responses among listed herbicides. Zero indicates the least potential for injury response; 1 indicates a tolerable response; 2 indicates the highest tolerable injury level.

For herbicide ratings for tank mixes or premixes, see the component parts:

Premix	Grass	Broadleaf
Broadstrike + Dual	Dual	Broadstrike
Broadstrike + Treflan	Trifluralin	Broadstrike
Commence	Trifluralin	Command
Passport	Trifluralin	Pursuit
Pursuit Plus	Prowl	Pursuit
Salute	Trifluralin	Sencor
Squadron	Prowl	Scepter
Tri-Scept	Trifluralin	Scepter
Turbo	Dual	Sencor

swollen lateral roots. Usually such injuries are not serious. If incorporation is too shallow or Prowl is applied to the soil surface, soybean stems may be calloused and brittle, leading to lodging or stem breakage.

DNA herbicides can sometimes injure rotational crops of corn or sorghum. Symptoms appear as reduced stands and stunted, purple plants with poor root systems. Under good growing conditions, corn typically recovers from this early season injury. Accurate, uniform incorporation is needed to minimize potential carryover.

Table 15.16. Soybean Postemergence Herbicides: Broadleaf Weed Control Ratings

Herbicide	PGW	LBQ	SMW	VLV	AMG	CCB	JMW	CRW	GRW	BCC	BNS	KCH	SFR	PSD	Soybean response[a]
Contact Postemergence															
Basagran	4	7	9	8+	4	9+	9	7	8	3	3	8	8	8	0
Galaxy	8	7	9	8+	6	9+	9	8	8	5	6	8	8	8	1+
Storm	9	6	9	7	7	8+	9	9	8	6	7	6	8	6	2
Blazer	9+	6	9	6	8	7	9	9	8	7	8	6	7	3	2
Cobra	9+	6	6	7	8	8	9	9	8	7	8	5	8	5	3
Reflex	9+	6	9	6	8	7	9	8	8	6	7+	5	7	2	1+
Systemic Postemergence															
Classic	8	2	8	8	7	9+	8+	8	7	8	2	4	9	2	1+
Pinnacle	9	8+	8	8+	4	6	4	5	4	2	2	7	6	2	2+
Concert	8+	8+	8	8+	6	9+	7	6	5	6	2	7	8	2	2+
Synchrony STS[b]	9	9	9	9	7	9+	8+	8	7	8	2	7	9	2	0
Pursuit	9	6	9	8+	7	8+	7	7	7+	6	9	8	9	6	1+
Scepter	9	4	6	3	3	9+	4	5	3	3	5	4	7	2	1

PGW = pigweeds, LBQ = lambsquarters, SMW = smartweeds, VLV = velvetleaf, AMG = annual morningglories, CCB = cocklebur, JMW = jimsonweed, CRW = common ragweed, GRW = giant ragweed, BCC = burcucumber, BNS = eastern black nightshade, KCH = kochia, SFR = wild sunflower, PSD = prickly sida. In weed columns, 10 = 95 to 100% control, 9 = 85 to 95%, 8 = 75 to 85%, 7 = 65 to 75%, 6 = 55 to 65%, 5 and below = insignificant control, + = control at the higher end of the range. Boldface indicates acceptable control.

[a] Ratings in this column compare crop injury responses among listed herbicides. Zero indicates the least potential for injury response; 1 indicates a tolerable response; 2 indicates the highest tolerable injury level; 3 indicates the need to question the use of this herbicide.

[b] Use only on sulfonylurea-tolerant (STS) soybean varieties.

Treflan, Tri-4, or Trific (trifluralin) may be applied alone anytime in the spring prior to planting. However, the labels for tank mixes may specify application closer to soybean planting. Incorporate trifluralin 2 to 3 inches deep within 24 hours after application. If the soil is warm and moist, it may be beneficial to incorporate sooner. The rate per acre is 1 to 2 pints of 4E or equivalent rates of Treflan 5 or 10G or Trific 60DF. A slightly higher rate and deeper incorporation may be specified for shattercane control.

Sonalan 3E (ethalfluralin) may be applied at 1.5 to 3 pints per acre within 3 weeks before planting and should be incorporated within 2 days after application. There is a greater risk of soybean injury from Sonalan than from trifluralin, so incorporation must be uniform. Sonalan is less likely than trifluralin to carry over and injure corn the following year.

Prowl 3.3E (pendimethalin) may be applied at 1.8 to 4.8 pints per acre up to 60 days (less for some tank mixes) before planting soybeans. Preplant treatments should be incorporated within 7 days unless adequate rainfall occurs to incorporate the herbicide. *South of Interstate 80,* Prowl may be applied preemergence up to 2 days after planting.

Command 4E (clomazone) is used at 1.5 to 2 pints per acre to control annual grasses, velvetleaf, and several other broadleaf weeds. Use the higher rate if Command is applied more than 30 days prior to planting. Command is also used at lower rates in some tank mixes for velvetleaf control. Command can be used preplant prior to *drilled no-till soybeans* if the drill is equipped with fluted or wavy coulters and spring tines or harrow to enhance incorporation. Plant at 6 miles per hour or more for adequate incorporation. Planting can be delayed 8 hours if the soil is dry, but plant immediately if the soil is moist. **Commence 5.25L** is a premix of Command and trifluralin used at 1.75 to 2.67 pints per acre.

Incorporate Command or Commence immediately if the soil is moist or within 8 hours after application if the soil is dry. *You must minimize drift (spray or vapor) to sensitive plants.* Do not apply within 100 feet of desirable trees, ornamentals, vegetables, alfalfa, or small grains or within 1,000 feet of subdivisions or towns, nurseries, greenhouses, and commercial fruit or vegetable (except sweet corn) production areas. See the Command label for a list of susceptible species.

Minimum recropping intervals are 9 months for field corn or milo and 12 months for wheat. See Table 15.02 or the label for more information. Carryover injury will appear as whitened or bleached plants after emergence. Corn has usually outgrown modest injury with little effect on yield. However, injury may be more severe if application or incorporation is not uniform. Corn hybrids and small grain varieties vary in tolerance to clomazone.

Dual (metolachlor), Frontier (dimethenamid) and Lasso, Micro-Tech, or Partner (alachlor) can be applied up to 30 days preplant incorporated or preemergence to control annual grasses and pigweeds. Use the higher rates to improve eastern black nightshade control and incorporate to improve yellow nutsedge control. They can be combined with other herbicides (Table 15.13) to improve broadleaf control. Dual rates per acre are 1.5 to 3 pints of 8E or 6 to 12 pounds of 25G. Frontier is applied at 13 to 25 fluid ounces per acre. Lasso or Micro-Tech is applied at 2 to 4 quarts per acre or equivalent rates of Lasso II 15G or Partner 65DF. *All products containing alachlor are restricted-use pesticides.*

Freedom 3E is an 8:1 premix of alachlor (Lasso) and trifluralin, so Freedom controls the same weeds as Lasso. Freedom is applied at 3.5 to 5 quarts per acre up to 7 days prior to planting and incorporated or after planting if within 5 days of last preplant tillage operation. *Freedom is a restricted-use pesticide.*

Soil-applied "broadleaf" herbicides (soybeans)

Broadstrike + Dual, Broadstrike + Treflan, Canopy, Command, Lexone, Lorox, Lorox Plus, Preview, Pursuit, Scepter, and Sencor are soil-applied herbicides used for broadleaf weed control in soybeans (see Table 15.15 for weeds controlled). Lorox is not to be incorporated, and Command should be incorporated unless applied early preplant. (Command is discussed in the "grass" herbicide section.) The others can be used preplant-incorporated or preemergence after planting soybeans.

Timely rainfall or incorporation is needed for uniform herbicide placement in the soil. Incorporation may improve control of deep-germinating (large-seeded) weeds, especially when soil moisture is limited. Accurate and uniform application and incorporation are essential to minimize potential soybean injury. Except for Command, these herbicides are photosynthetic inhibitors (PSI), meristematic inhibitors (MSI), or premixes of MSI (chlorimuron) and PSI (metribuzin or linuron).

Photosynthetic inhibitors

Metribuzin (Sencor or Lexone) and linuron (Lorox) are photosynthetic inhibitors (PSI). Preview, Salute, and Canopy are premixes that contain metribuzin, whereas Lorox Plus is a premix that contains linuron. These PSI herbicides cause severe soybean injury from foliar application, *so do not apply them after soybeans emerge.* They occasionally injure soybeans from soil uptake.

PSI herbicide injury symptoms are intervenal chlorosis (yellowing) of the leaf margins and necrosis (dying) of the lower soybean leaves, usually appearing at about the first trifoliate stage. Atrazine and simazine carryover can intensify these symptoms. Soybeans usually recover from moderate PSI injury that occurs early. Metribuzin injury may be greater on soils with pH over 7.0. Soybean varieties differ in their sensitivity to metribuzin.

Sencor or Lexone (metribuzin) may be applied anytime within 14 days before planting soybeans. The Sencor or Lexone rate per acre used in tank mixes is ½ to 1 pint of 4L or ⅓ to ⅔ pound of 75DF. Accurately adjust the rates according to soil texture and organic matter content. *Do not apply to sandy soil that is low in organic matter. Do not use on soils with pH greater than 7.5.* Reduced rates minimize soybean injury but lessen weed control. Split preplant and preemergence applications allow higher rates to improve weed control. Sencor or Lexone can be tank-mixed with several herbicides to control annual grasses (Table 15.13).

Turbo 8E, a premix of metribuzin (Sencor) plus metolachlor (Dual), can be applied preplant-incorporated or preemergence. The rate is 1.5 to 3.5 pints per acre.

Salute 4E, a premix of metribuzin (Sencor) plus trifluralin (Treflan), is applied preplant at 1.5 to 3 pints per acre and must be incorporated within 24 hours.

Preview 75DF and Canopy 75DF are premixes of metribuzin (Lexone) and chlorimuron (Classic), whereas **Lorox Plus 60DF** is a premix of linuron (Lorox, see next entry) and chlorimuron (Classic). These premixes may be applied preemergence or preplant-incorporated. They control cocklebur, velvetleaf, and wild sunflower better than metribuzin or linuron alone (see Table 15.15). Combinations with the grass herbicides can improve grass control (see Tables 15.13 and 15.14).

Broadcast rates per acre are 6 to 10 ounces of Preview 75DF, 4 to 7 ounces of Canopy 75DF, and 12 to 18 ounces of Lorox Plus 60DF. *Do not apply Preview, Canopy, or Lorox Plus to soils with pH greater than 6.8.* High soil pH may occur in localized areas in a field. Correct rate selection for the soil plus uniform, accurate application and incorporation are essential to minimize soybean injury and potential follow-crop injury. See PSI injury symptoms (just described) and MSI injury symptoms (in the next section).

Minimum recropping intervals for Preview, Canopy, and Lorox Plus are 4 months for wheat and 10 months for field corn. If Classic, Pursuit, or Scepter is applied the same year as Preview, Canopy, or Lorox Plus, the risk of carryover can increase, so labels should be checked carefully for rotational guidelines.

Lorox or Linex (linuron) is used after planting soybeans and before the crop emerges. Linuron is best suited to the silt loam soils of southern Illinois that contain 1 to 3 percent organic matter, where the rate per acre is 1 to 1⅔ pounds of 50DF. *Do not apply to very sandy soils or soils containing less than 0.5 percent organic matter.*

Command (clomazone) is often used as a broadleaf herbicide in tank mixes, but it also controls annual grasses. Command is a pigment inhibitor; secondary effects on photosynthesis may occur. See the earlier discussion under "Soil-Applied Grass Herbicides (Soybeans)."

ALS meristematic inhibitors

Imazethapyr (Pursuit), imazaquin (Scepter), chlorimuron (in Canopy, Preview, and Lorox Plus; see the discussion in the previous section), and flumetsulam (Broadstrike) are meristematic inhibitors (MSI). See Table 15.15 for weeds controlled. MSI herbicide injury symptoms include temporary yellowing of upper leaves (golden tops) and shortened internodes of soybeans. Although plants may be stunted, yield is generally not affected. Some of these MSI herbicides may carry over and injure certain sensitive follow crops. Symptoms on corn or grain sorghum are stunted growth, inhibited roots, and interveinal chlorosis or purpling of leaves. Symptoms on small grains are stunted top growth and excess tillering.

Pursuit 2S or Pursuit 70DG (imazethapyr) is used at 4 fluid ounces per acre (1 gallon per 32 acres) or 1.4 ounces per acre (1 bag per 5 acres), respectively, to control broadleaf weeds (see Table 15.15). Velvetleaf and jimsonweed control are more consistent with

incorporation. Grass control is improved by tank-mixing Pursuit with a grass herbicide (see Table 15.13). **Pursuit Plus and Passport** are both premixes of Pursuit, with Prowl or trifluralin, respectively. Both are used at 2.5 pints per acre, which is equivalent to 0.25 pint of Pursuit plus 2.1 pints of Prowl 3.3L or 0.25 pint of Pursuit plus 1.5 pints of trifluralin, respectively.

Pursuit and Pursuit Plus can be applied up to 45 days prior to planting soybeans. If sufficient rain does not occur before planting, then incorporate mechanically. *South of Interstate 80,* Pursuit Plus can be surface-applied up to 2 days after soybean planting. Minimum recropping intervals for Pursuit, Pursuit Plus, and Passport are 4 months for wheat, 8.5 months for field corn, and 18 months for grain sorghum. Pursuit has less potential than Scepter to injure corn the next season and provides better control of velvetleaf. Thus, Pursuit is more adapted than Scepter to most soils of central and northern Illinois.

Scepter (imazaquin) is used at ⅔ pint 1.5E or 2.8 ounces of 70DG per acre and, if incorporated, is applied within 45 days (less with many tank mixes) before planting. Surface applications may be made up to 45 days before planting, during planting, or after planting but before the crop emerges. Scepter controls many broadleaf weeds, such as pigweeds and cocklebur (see Table 15.15), with adequate soil moisture, but it is somewhat weak on velvetleaf. Incorporation can improve weed control under low-rainfall conditions, and may improve control of velvetleaf and giant ragweed. Grass control is improved by mixing with "grass" herbicides (see Table 15.13).

Squadron and Tri-Scept are premixes of imazaquin (Scepter) plus pendimethalin (Prowl) or trifluralin, respectively. The rate per acre is 3 pints of Squadron or 2.33 pints of Tri-Scept, which is the equivalent of ⅔ pint of Scepter plus 1.5 pints of Prowl or trifluralin. Incorporate Squadron within 7 days unless sufficient rain occurs. Tri-Scept must be incorporated within 24 hours.

A line across Peoria, extending west along Illinois Route 116 and east along U.S. Route 24, delineates Scepter, Squadron, and Tri-Scept rotational crop restrictions in Illinois (Table 15.02). Region 3 is north of the line; Region 2 is south.

There have been significant problems with carryover of Scepter and related premixes and tank mixes in Illinois. Soil and climatic conditions plus lack of uniformity in application and incorporation are associated with the carryover problem.

The potential for carryover is greater on soils with high organic matter and low pH. Research and field results indicate that in Illinois Scepter, Squadron, and Tri-Scept are best adapted to the soils and weeds south of Interstate 70. Reduced rates, which can reduce potential carryover, are allowed for postemergence use of Scepter and in tank mixes with several other products. Imidazolinone-tolerant or -resistant corn hybrids can be used to minimize carryover problems.

Broadstrike + Dual 7.67E (flumetsulam + metolachlor) can be applied at 1.75 to 2.5 pints per acre up to 14 days prior to planting and incorporated (no hurry) or immediately after planting soybeans. **Broadstrike + Treflan 3.65E (flumetsulam + trifluralin)** can be applied at 1.5 to 2.25 pints per acre up to 30 days prior to planting soybeans. Uniformly incorporate into the top 2 to 3 inches of soil within 24 hours after application.

Postemergence herbicides (soybeans)

Postemergence (foliar) herbicides are more effective when used in a planned program so that application is timely and not just an emergency or rescue treatment. Foliar treatments allow the user to identify the problem weed species and choose the most effective herbicide. See Tables 15.14 and 15.16 for weed control ratings with various soybean herbicides.

Rates and timing for foliar treatments are based on weed size. Early application, when weeds are young, may allow the use of lower herbicide rates. Treatment of oversized weeds may suppress growth only temporarily, and regrowth may occur. A cultivation 7 to 14 days after application but before regrowth can often improve weed control. However, cultivation during or within 7 days of a foliar application may cause erratic weed control. Tables 15.17, 15.18, and 15.19 give the soybean herbicide rate for labeled weed sizes. Table 15.20 gives tank mixes labeled for postmergence weed control in soybeans.

Crop oil concentrate (COC) or nonionic surfactant (NIS) is usually added to the spray mix to improve postemergence herbicide effectiveness. A COC can be either petroleum oil (POC)– or vegetable oil (VOC)–based. Dash is a special surfactant primarily for use with Poast Plus. Fertilizer adjuvants such as 28-0-0 (urea-ammonium nitrate) or ammonium sulfate (AMS) may be specified on the label to increase control of certain weed species, such as velvetleaf. Table 15.21 lists adjuvants labeled with various postemergence soybean herbicides, reentry intervals, and rain-free periods for optimum postemergence activity. Rainfall soon after application can cause poor weed control. Warm temperatures and high relative humidity greatly increase foliar herbicide activity. Weeds growing under drouthy conditions are more difficult to control.

Postemergence herbicides for soybeans are either contact or translocated in action. Contact herbicides initially affect only the leaf tissue covered by the spray, so thorough spray coverage is critical. Contact herbicides should be applied when weeds are small. Injury symptoms are usually noticeable within a day. Translocated herbicides do not require complete spray coverage because they move to the growing points (meristems) after foliar penetration. Their action is slow, and symptoms may not appear for a week.

Contact herbicides for postemergence control of broadleaf weeds (soybeans)

Basagran, Blazer, Reflex, Cobra, Galaxy, and Storm are contact broadleaf herbicides. See Table 15.16 for

weeds controlled. Table 15.17 gives herbicide rates by weed height. Spray volume for ground application is 10 to 30 gallons per acre, and spray pressure should be 40 to 60 psi. Hollow-cone or flat-fan nozzles provide much better coverage than flood nozzles.

Low temperatures and humidity will reduce contact herbicide activity. Soybean leaves may show contact burn under conditions of high temperature and humidity. This leaf burn is intensified by crop oil concentrate or Dash. Soybeans usually recover within 2 to 3 weeks after application. A rain-free period of several hours is required for effective control with most contact herbicides.

Smaller weeds that are actively growing may allow the use of reduced herbicide rates. Most contact herbicides have little soil residual activity, so do not apply too early. Apply 2 to 3 weeks after soybean emergence or when soybeans are in the one- to two-trifoliate stage. Larger weeds not only require increased rates, but the weeds may recover and regrow. Contact herbicides should not be applied after soybeans begin to bloom. Preharvest intervals are generally 50 to 90 days.

Basagran (bentazon) is used at 1 to 2 pints per acre. See Table 15.17 for specifics on weed heights and application rates. Most weeds should be small (1 to 3 inches) and actively growing. Velvetleaf control is improved if 28-0-0 (urea-ammonium nitrate) is added to the spray mixture. Crop oil concentrate is preferred if the major weed species is common ragweed or lambsquarters. Split applications can improve control of lambsquarters, giant ragweed, wild sunflower, and yellow nutsedge. Adding 2,4-DB can improve annual morningglory control. Do not spray if rain is expected soon after application.

Blazer (acifluorfen) is used at 0.5 to 1.5 pints per acre when broadleaf weeds are 2 to 4 inches tall and actively growing. Split applications are allowed 15 days apart, but do not apply more than 2 pints per acre per season. See the label or Table 15.21 for

Table 15.17. Postemergence Contact Herbicide Rates for Weed Heights or Growth Stages in Soybeans

	Basagran		Blazer		Galaxy		Storm		Cobra		Reflex	
Weed	Height (in.)	Rate (pt/acre)	Height (in.)	Rate (pt/acre)	Height (in.)	Rate (pt/acre)	Height (in.)	Rate (pt/acre)	Stage (leaves)	Rate (fl oz/acre)	Stage (leaves)	Rate (pt/acre)
AMG	. . .	. . .	2 4	1.0 1.5	2	2	2	1.5	2	12.5	2	1.25[a]
CCB	4 6 10	1 1.5 2	2	1.5	6	2	6	1.5	6	12.5	2	1.25[a]
JMW	4 6 10	1 1.5 2	4 6	1.0 1.5	6	2	6	1.5	4	12.5	4 6	1.00 1.25[a]
LBQ[b]	1 2	1 2	2	1.5	2	2	2	1.5	. . .	. . .	2	1.25[a]
BNS	. . .	. . .	<2 2	1.0 1.5	<2	2	2	1.5	6	12.5	4 4	1.00 1.25[a]
PGW	. . .	. . .	<4 4	1.0 1.5	2	2	2 to 3	1.5	6	12.5	4 6	1.00 1.25[a]
CRW	3	2	2 3	1.0 1.5	3	2	3	1.5	6	12.5	4 4	1.00 1.25[a]
GRW	6	2	<2 3	1.0 1.5	6	2	6	1.5	4	12.5	. . .	. . .
SMW	4 6 10	1.0 1.5 2	4 6	1.0 1.5	6	2	6	1.5	. . .	. . .	4 4	1.00 1.25[a]
SFR	3 5 8	1 1.5 2	. . .	. . .	5	2	. . .	. . .	2	12.5	. . .	. . .
PSI	3 4	1.5 2	. . .	. . .	3	2	2	1.5	4	12.5	. . .	. . .
VLV	2 5 6	1.0 1.5 2.0	. . .	. . .	5	2	2	1.5	4	12.5	. . .	. . .
YNS[c]	6 8	1.5 2	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

AMG = annual morningglories (tall and ivyleaf), CCB = common cocklebur, JMW = jimsonweed, LBQ = lambsquarters, BNS = eastern black nightshade, PGW = pigweeds, CRW = common ragweed, GRW = giant ragweed, SMW = smartweeds, SFR = wild sunflower, PSD = prickly sida, VLV = velvetleaf, YNS = yellow nutsedge, . . . = not on label.
[a] Reflex at 1.25 pt/acre to be applied south of Interstate 70 only.
[b] Control of lambsquarters is often inconsistent with contact herbicides.
[c] May need to repeat application for complete control.

adjuvant use, and see Table 15.17 for application rates and weed heights. Velvetleaf control is improved with the use of fertilizer adjuvants or the addition of Basagran. Adding 2,4-DB can improve cocklebur and morningglory control. Blazer may cause soybean leaf burn. However, the crop usually recovers within 2 to 3 weeks. Do not spray if rain is expected within 4 to 6 hours.

Basagran plus Blazer improves control of pigweeds and morningglories over Basagran alone. **Storm 4S and Galaxy 3.67S** are premixes of Basagran and Blazer. Storm at 1.5 pints per acre is equivalent to 1 pint of Basagran plus 1 pint of Blazer. Galaxy at 2 pints per acre is equivalent to 1.5 pints of Basagran plus 0.67 pint of Blazer. Galaxy is labeled at up to 3 pints per acre for suppression of weeds larger than the sizes given on the label. See the labels or Table 15.21 for adjuvant specifics, and see Table 17 for weed heights.

Cobra 2E (lactofen) is applied alone at 12.5 fluid ounces per acre. See Table 15.17 for weeds controlled. Cobra is applied in tank mixes at 6 to 12.5 fluid ounces per acre to improve control of giant and common ragweed as well as morningglory. See the Cobra label for details on adjuvant selection, which varies with relative humidity (used alone) and with the tank-mix partner. Cobra can cause severe soybean leaf burn, but soybeans usually recover within 2 to 3 weeks. Apply Cobra no later than 90 days before harvest.

Reflex 2LC (fomesafen) is used at 0.75 to 1 pint per acre north of Interstate 70 and at 1.25 pints south of Interstate 70. **Tornado (fomesafen + fluazifop-P)** is used at 1 quart per acre (equivalent to 1 pint of Reflex and 0.75 pint of Fusilade DX 2E) to control broadleaf and grass weeds. Add crop oil concentrate or nonionic surfactant with Reflex or Tornado.

Reflex or Tornado should be applied before soybeans bloom. Do not spray if rain is expected within 4 hours of application. Be sure applications are accurate and even, as there is a potential for carryover with fomesafen. Do not apply Reflex or Tornado to any field more than once every 2 years. Recrop intervals are 4 months for small grains, 10 months for corn, and 18 months for other crops.

Translocated herbicides for postemergence control of broadleaf weeds (soybeans)

Classic, Pinnacle, Pursuit, and Scepter are translocated herbicides that inhibit the acetolactate synthase (ALS) enzyme. They primarily control broadleaf weeds (Table 15.16), although Pursuit provides some grass control (Table 15.14). Table 15.18 lists herbicide rates by weed species and heights. Weeds should be actively growing (not moisture- or temperature-stressed). Do not make applications when weeds are in the cotyledon stage. Annual weeds are best controlled when less than 3 to 5 inches tall (within 2 to 4 weeks after soybean emergence). A 1-hour rain-free period after application is adequate for these ALS herbicides.

The ALS herbicides inhibit growth of new meristems, so symptoms of weed injury may not be exhibited for 3 to 7 days after application. Injury symptoms are yellowing of leaves followed by death of the growing point. Death of leaf tissue in susceptible weeds is usually observed in 7 to 21 days. Less susceptible plants may be suppressed, remaining green or yellow but stunted for 2 to 3 weeks.

Soybeans may show temporary leaf yellowing ("golden tops"), growth retardation (generally in the form of shortened internodes), or both, especially if soybeans are under stress. Under favorable conditions, affected soybeans may recover with only a slight reduction in height and no loss of yield.

Total spray coverage is less critical for translocated herbicides than for contact herbicides. A minimum spray volume of 10 gallons per acre may be used for ground application using flat-fan nozzles at 20 to 40 psi or hollow-cone nozzles at 40 to 60 psi. Nonionic surfactant (NIS) is usually specified at 1 to 2 pints per 100 gallons of spray. Crop oil concentrate (COC) may improve weed control but may increase crop injury. Fertilizer additives (such as UAN or 10-34-0) improve control of some weeds and are specified for velvetleaf control on the Classic, Pinnacle, and Pursuit labels. *Tank-mixing these herbicides with postemergence herbicides for grass may reduce grass control, so sequential applications are often specified.* Table 15.20 lists labeled tank mixes but not herbicides labeled for sequential application.

Classic 25DF (chlorimuron) is used at 0.5 to 0.75 ounce per acre plus 1 quart NIS or 1 gallon COC per 100 gallons. Fertilizer adjuvants improve velvetleaf control. Pigweed control varies with rate and species. Check the label or Table 15.18 for weed heights and application rates. Split applications can improve control of burcucumber, giant ragweed, and annual morningglories. Do not apply Classic within 60 days of harvest. Recrop intervals are 3 months for small grains and 9 months for field corn, sorghum, alfalfa, or clover. If Classic is applied after Preview, Canopy, Lorox Plus, Pursuit, or Scepter, check the label for recrop intervals, as carryover injury to corn can occur, especially if soil pH is above 6.8. Corn will appear stunted with interveinal chlorosis or purpling of leaves and inhibition of roots.

Pinnacle 25DF (thifensulfuron) is used at 0.25 ounce per acre to control lambsquarters, pigweeds, smartweeds, and velvetleaf. See Table 15.18 for weed heights. The addition of 1 gallon of UAN per acre improves velvetleaf control. Tank-mixing 0.25 ounce of Classic 25DF per acre with Pinnacle can improve control of cocklebur, jimsonweed, and wild sunflower. Add NIS at 1 to 2 pints per 100 gallons. *Do not use COC unless conditions are drouthy. Do not use Dash.* Pinnacle has less soil persistence than Classic. Any crop may be planted 45 days after application of Pinnacle alone. For Concert or a Classic + Pinnacle tank mix, the Classic recropping intervals apply.

Concert 25DF (1:1 ratio of chlorimuron and thifensulfuron) is used at 0.5 ounce per acre to control

Table 15.18. Postemergence Translocated Herbicide Rates for Broadleaf Weed Heights in Soybeans

	Classic		Pinnacle[a]	Concert[b]	Synchrony STS[c]	Pursuit[d,e]	Scepter	
Weed	Height (in.)	Rate (oz/acre)	Height (in.)	Height (in.)	Height (in.)	Height (in.)	Height (in.)	Rate[c] (pt/acre)
AMG	1–2	0.50	. . .	1–2	1–3	1–2	. . .	. . .
	1–3	0.66						
	1–4	0.75						
CCB	2–6	0.50	2–6[f]	2–4	2–8	1–8	1–8	0.33
	2–8	0.66					9–12	0.66
	2–12	0.75						
JMW	2–4	0.50	2–4[f]	2–5	2–5	1–3	. . .	. . .
	2–6	0.75						
LBQ	. . .	. . .	2–4	2–4	2–4	1–2	. . .	. . .
BNS	. . .	. . .	. . .	. . .	. . .	1–3	. . .	. . .
PGW	1–2	0.50[g]	2–12	2–12	2–8	1–8	1–4	0.33
	1–3	0.66[g]					5–12	0.66
	1–4	0.75[g]						
CRW	2–3	0.66	. . .	1–3[d]	2–4	1–3	. . .	. . .
	2–4	0.75						
GRW	2–6	0.75	. . .	. . .	2–4[f]	1–3	. . .	. . .
SMW	1–2	0.50	2–6	2–8	. . .	1–3	. . .	. . .
	1–3	0.66						
	1–4	0.75						
SFR	2–5	0.50	2–6[f]	2–8	. . .	1–3	1–4	0.33
	2–6	0.66					5–8	0.66
	2–8	0.75						
VLV	2–4	0.66	2–6	2–8	. . .	1–3	. . .	. . .
	2–6	0.75						
YNS	2–3	0.50	. . .	. . .	. . .	1–3	. . .	. . .
	2–4	0.75						

AMG = annual morningglories (tall and ivyleaf), CCB = common cocklebur, JMW = jimsonweed, LBQ = lambsquarters, BNS = eastern black nightshade, PGW = pigweeds, CRW = common ragweed, GRW = giant ragweed, SMW = smartweeds, SFR = wild sunflower, VLV = velvetleaf, YNS = yellow nutsedge, . . . = not on label.

[a] For all weeds and heights, rate is 0.25 oz/acre.

[b] For all weeds and heights, rate is 0.5 oz/acre. Or can use 0.25 oz/acre of Pinnacle + 0.25 oz/acre of Classic.

[c] For all weeds and heights, rate is 0.85 oz/acre. Or can use 0.25 oz/acre of Pinnacle + 0.60 oz/acre of Classic.

[d] For all weeds and heights, rate is 4 fl oz/acre.

[e] Or equivalent rates of 70DG formulation.

[f] Suppression only.

[g] Redroot pigweed only; smooth pigweed and tall waterhemp only suppressed.

velvetleaf, pigweeds, lambsquarters, cocklebur, wild sunflower, and jimsonweed. Add NIS at 1 to 2 pints per 100 gallons. COC at 4 pints per 100 gallons may be substituted for NIS under dry conditions. Do not use Dash.

Synchrony STS 25DF (2.4:1 ratio of chlorimuron and thifensulfuron) is to be used only on STS (sulfonylurea-tolerant) soybeans at 0.85 ounce per acre (3.4 ounce soluble pack per 4 acres). Weed species and heights are listed in Table 15.18. The higher chlorimuron rate controls larger cocklebur than Concert does, plus it controls small giant ragweed and suppresses common milkweed, Canada thistle, and yellow nutsedge. Use COC plus an ammonium fertilizer adjuvant, *except consult the label when tank-mixing with Cobra or 2,4-DB.* A tank mix of Synchrony STS with 1 to 2 fluid ounces of 2,4-DB after soybeans are 8 inches tall improves control of up to 4-inch tall giant ragweed or annual morningglories. See Table 15.02 for recropping intervals after Synchrony STS application.

Pursuit (imazethapyr) is used at 4 fluid ounces of 2S or 1.4 ounce of 70DF per acre plus COC or NIS. Add 1 quart of UAN or 2.5 pounds of ammonium sulfate per acre. (See Table 15.18 for weed heights.) Lambsquarters, common ragweed, and annual morningglory control may be poor. Pursuit can provide control of foxtails and shattercane but not volunteer corn. Do not apply Pursuit within 85 days of soybean harvest. Recropping intervals are 4 months after application for wheat, 8.5 months for field corn, and 18 months for other field crops, including milo (Table 15.02). Do not apply products containing chlorimuron or imazaquin the same year as Pursuit because such combinations increase the potential for injury to subsequent crops.

Scepter (imazaquin) can be used postemergence to control pigweeds, cocklebur, wild sunflower, and volunteer corn in soybeans. The low rate per acre is ⅓ pint of 1.5E or 1.4 ounces of 70DG. A higher rate is labeled, but rotational guidelines change. Scepter is better on cocklebur and volunteer corn, but Pursuit is better on velvetleaf and shattercane. Use NIS at 2 pints per 100 gallons of spray or COC at the rate on the COC label. Do not tank-mix Scepter with postemergence herbicides for grass control. Do not apply Scepter within 90 days of soybean harvest. Follow rotational guidelines on the Scepter label or see Table 15.02. Also see the recrop discussion on Scepter in the earlier section on "Soil-Applied 'Broadleaf' Herbicides (Soybeans)."

Scepter O.T. is a premix combination with 0.5 pound a.i. of imazaquin and 2 pounds a.i. acifluorfen per gallon to broaden the spectrum of control to include

annual morningglories, copperleaf, and smartweeds. The rate is 1 pint per acre plus 1 quart NIS per 100 gallons. The addition of 1 to 2 fluid ounces of 2,4-DB to Scepter O.T. may further improve control of annual morningglories.

Translocated herbicides for control of grass weeds (soybeans)

Poast Plus, Assure II, Fusilade DX, Fusion, and Select can control many annual and perennial grasses in soybeans (Table 15.14). Table 15.19 gives herbicide rates by grass weed heights. Pursuit also has some postemergence grass control. Grasses should be actively growing (not stressed or injured) and not tillering or forming seedheads. Cultivation within 5 to 7 days before or after application may decrease grass control. All except Poast Plus allow use of a crop oil concentrate or nonionic surfactant (see Table 15.21 for adjuvant use). However, a crop oil concentrate (or Dash with Poast Plus) is usually preferred if weeds are somewhat drouthy or if maximum weed heights are approached.

Rates vary by weed heights and species, so consult the label or Table 15.19 before applying. Rate reductions may be optional on small weeds or under ideal conditions, whereas rate increases may be needed for larger weeds. Control of johnsongrass and quackgrass often requires follow-up applications for control of regrowth. Volunteer cereals such as wheat and rye can be controlled by Assure II, Fusion, or Fusilade; Poast Plus or Select can provide good control if the plants have not tillered or overwintered.

Specified spray volume per acre is 10 to 20 gallons for ground application or 3 to 5 gallons for aerial application. A 1-hour rain-free period after application is needed. Avoid drift to sensitive crops such as corn, sorghum, and wheat. Apply before soybeans bloom and at least 60 to 90 days before harvest.

These herbicides do not control broadleaf weeds. Most labels allow tank-mixing with certain broadleaf herbicides, but limitations are made as to rate, timing, and spray coverage. *Check the label before applying grass and broadleaf herbicide tank mixes or sequences. Control of grass weeds may be reduced, or increased rates may be specified.*

Poast Plus 1.0E (sethoxydim) is labeled at 24 ounces (1.5 pints) per acre for foxtails up to 8 inches, shattercane up to 18 inches, volunteer corn up to 20 inches. See the label or Table 15.19 for weed heights and special rates for smaller or larger weeds. Fertilizer adjuvants are specified for control of volunteer corn and shattercane. Always add 2 pints per acre of Dash or crop oil concentrate (COC). **Rezult and Conclude** are packaged delivery systems of 1:1 Poast plus Basagran (bentazon) or Storm (bentazon + aciflurofen), respectively. The rates per acre are 3.5 pints of Rezult and 3 pints of Conclude. See the upcoming "Problem Perennial Weeds" section for control of perennial grasses.

Assure II 0.88E (quizalofop) is used at 7 to 9 fluid ounces per acre to control most annual grass species, including crabgrass, foxtails, and fall panicum. Tank mixes of Assure II with "broadleaf" herbicides reduce control of several grass species (Table 15.19), while an increased rate is recommended for some other grass species when tank-mixing. If split-applied, Assure II can be applied either 24 hours before or 7 days after the "broadleaf" herbicide. Use 5 fluid ounces per acre to control volunteer corn or shattercane. Add either 1 gallon of petroleum crop oil concentrate or 1 quart of nonionic surfactant per 100 gallons of spray. Refer to the label or Table 15.19 for rates and weed sizes. See the upcoming "Problem Perennial Weeds" section for perennial grass control.

Fusilade DX 2E (fluazifop-P) is applied at 6 fluid ounces per acre for volunteer corn, shattercane, or seedling johnsongrass. Refer to the label or Table 15.19 for weed sizes and rates. Add either 1 gallon of COC or 1 quart of nonionic surfactant (NIS) per 100 gallons of spray. See the upcoming "Problem Perennial Weeds" section for control of perennial grasses.

Fusion 2.66E (fluazifop + fenoxaprop) is a premix of Fusilade and Option. The rate is 6 to 8 fluid ounces per acre when used alone or 8 to 10 fluid ounces when tank-mixed. Reduced rates are allowed on susceptible weeds when applied under optimum growing conditions. See Table 15.19 for maximum height limitations and rates. Always add COC or NIS with Fusion.

Select 2E (clethodim) is used to control annual grasses at 4 to 6 fluid ounces per acre when used alone or 6 to 8 fluid ounces when tank-mixed with a broadleaf herbicide. Add 1 quart per acre of COC. Use the lower rate under minimum grass pressure and/or when grasses are less than maximum height. Nitrogen fertilizer solution at 1 quart per acre may enhance control of large grasses and volunteer corn. Table 15.19 lists rates and grass height limits. Rhizome johnsongrass and quackgrass will require higher rates and may require two applications (see the upcoming "Problem Perennial Weeds" section).

Pursuit (imazethapyr) is used at 4 fluid ounces of 2S or 1.4 ounces of 70DG per acre to control barnyardgrass, crabgrass, foxtail, shattercane, and seedling johnsongrass (see Table 15.19 for weed heights). Add COC plus ammonium fertilizer adjuvant.

Roundup (glyphosate) may be applied through wiper applicators to control volunteer corn, shattercane, and johnsongrass. Hemp dogbane and common milkweed may also be suppressed. Weeds should be at least 6 inches taller than the soybeans to avoid contact with the crop. Adjust the height of the applicator so that the wiper contact is at least 2 inches above the soybean plants. Mix 1 gallon of Roundup with 2 gallons of water for wiper applicators. Spot treatment can be made on a spray-to-wet basis using a 2 percent solution of Roundup in water. Motorized spot treatment may provide less complete spray coverage of weeds, so use a 5 percent solution of Roundup. Minimize spray contact with the soybeans.

Table 15.19. Grass Weed Heights and Application Rates for Treatment with Postemergence Herbicides for Soybeans

Grass weed	Assure II		Fusilade DX		Fusion		Poast Plus		Select		Pursuit	
	Height[a]	Rate[b]	Height[a]	Rate[b]	Height[a]	Rate[b,c]	Height[a]	Rate[b]	Height[a]	Rate[b,c]	Height[a]	Rate[b]
Annuals												
Barnyardgrass	2–6	8[d]	2–3	12	2–4	8	1–4 ≤8	18 24	1–4 2–6	4 6	1–3	4
Crabgrass[a]	2–6	8[d]	1–2	12	1–4	8	≤6	24	1–3 2–6	4 6	1–3	4
Fall panicum	2–6	7[c]	2–6	12	2–6	8	1–4 ≤8	18 24	1–4 2–6	4 6	. . .	. . .
Giant foxtail	2–8	7	2–6	12	2–8	7	1–4 ≤8	18 24	1–4 2–12	4 6	1–6	4
Yellow foxtail	2–4	7[d]	2–4	12	2–3	8	≤8	24	1–4 2–8	4 6	1–3	4
Woolly cupgrass	2–4	9[d]	2–4	12	2–4	8	≤8	24	2–8	6	1–3	4
Sandbur	2–6	7[c]	2–4	12	2–4	8	≤3	30	2–6	6	. . .	. . .
Shattercane	6–12	5	6–12	6[c]	6–12	6	6–18	24	4–10 6–18	4 6	1–8	4
Volunteer corn	6–18	5	12–24	6[c]	12–24	6	1–12 12–20	18 24	4–12 12–24	4 6	. . . . . .	
Volunteer cereal	2–6	7[c]	2–6	8	2–6	8	≤4	36	2–6	6	. . .	. . .
Downy brome	. . .	. . .	2–6	8	2–6	6	. . .	. . .	. . .	. . .	. . .	. . .
Perennials												
Johnsongrass (seedling)	2–8	5	2–8	6	2–8	6	≤8	24	4–10	6	1–8	4
Johnsongrass (1st application)	10–24	10	8–18	12[c]	. . .	. . .	15–25	24	12–24	8	1–8	4
Regrowth (2nd application)	6–10	7	6–12	8	. . .	. . .	6–12	24	6–10	6	. . .	. . .
Quackgrass (1st application)	6–10	10[d]	6–10	12[c]	. . .	. . .	6–8	36	4–8	8	. . .	. . .
Regrowth (2nd application)	4–8	7	≤10	8	. . .	. . .	6–8	24	4–8	8	. . .	. . .
Wirestem muhly (ist application)	4–8	8[d]	4–12	12[c]	. . .	. . .	≤6	30	4–8	8	. . .	. . .
Regrowth (2nd application)	4–8	7	4–12	12	. . .	. . .	≤6	30	4–8	8	. . .	. . .

[a] In inches.
[b] In fluid ounces per acre.
[c] Add 2 fl oz when tank-mixing with broadleaf herbicides or if weeds are drouthy or have reached their maximum growth stage.
[d] For best results on these grasses, do not tank-mix with broadleaf herbicides.
[e] Length of lateral growth, not height.

Table 15.20. Postemergence Herbicide Tank Mixes for Soybeans

	Basagran	Blazer	Galaxy	Reflex	Cobra	Pinnacle	Classic	Concert	Synchrony STS	Pursuit
Registered for Broadleaf Weed Control in Soybeans										
Basagran	—	X	—	X	X	X	X	X	—	X
Cobra	X	—	—	—	—	X	X	—	X	X
Classic	X	X	X	X	X	X	—	—	—	—
Scepter	X	X	X	X	X	—	—	—	—	X
Pursuit[a]	X	X	X	X	X	X	—	—	—	X
Pinnacle	X	X	X	X	X	—	X	—	—	X
2,4-DB	X	X	X	X	X	—	X	—	X	X
Registered for Grass + Broadleaf Weed Control in Soybeans [b]										
Assure II	X	—	—	—	X	X	X	X	X	X[c]
Fusilade DX	X	X	—	X	X	X	X	X	X	X[c]
Fusion	X	X	X	X	—	X	X	X	X	X[c]
Poast Plus	X	X	X	—	—	—	X	X	X	X
Select	X	X	X	X	X	X	X	X	X	X

X = registered; — = not registered.
[a] Pursuit also controls several grass species.
[b] Check labels for special instructions. Sequential application may be preferable.
[c] To improve volunteer corn and shattercane control only.

Table 15.21. Soybean Postemergence Herbicides: Adjuvants, Rainfastness, Reentry Interval, and Preharvest Interval

Herbicide	Adjuvants and nitrogen	Rain-free period (hr)	Reentry interval (hr)	Preharvest interval (days)
No-Till				
2,4-D ester	None	1–2	12	NA
2,4-D amine	None	6–8	48	NA
Gramoxone	POC or VOC	0.5	12	NA
Roundup	NIS plus AMS	6	12	NA
Postemergence Grass				
Assure II	POC or NIS	1	12	80
Fusilade DX	POC, VOC, or NIS plus UAN	1	12	Prebloom
Fusion	POC, VOC, or NIS plus UAN	1	24	Prebloom
Poast Plus	POC[a] or VOC[a] plus UAN or AMS	1	12	75
Select	POC or VOC plus UAN	1	12	60
Postemergence Broadleaf, Contact				
Basagran	POC or VOC; adding UAN or AMS is optional	8[b]	48	None
Blazer	NIS, UAN, or AMS	6[b]	48	50
Cobra	POC, VOC, NIS, UAN, or AMS	0.5	12	90
Galaxy	POC, VOC, UAN, or AMS	8[b]	48	50
Reflex	POC, VOC, or NIS; adding UAN or AMS is optional	4	24	Prebloom
Storm	POC, VOC, NIS, or UAN	8[b]	48	50
Postemergence Broadleaf, Systemic				
2,4-DB	None[c]	6–8	48	60
Classic	POC, methylated seed oil, or NIS plus UAN or AMS	1	12	60
Concert	POC (if drouthy or cool) or NIS plus UAN or AMS	1	12	60
Pinnacle	POC (if drouthy or cool) or NIS plus UAN or AMS	1	12	60
Pursuit	POC, VOC, or NIS plus UAN or AMS	1	12	85
Roundup[d]	NIS; adding AMS is optional	6	12	Prebloom
Scepter	POC, VOC, or NIS	1	12	90
Synchrony STS	POC or methylated seed oil plus UAN or AMS	1	12	60

POC = petroleum oil concentrate, VOC = vegetable oil concentrate, NIS = nonionic surfactant, UAN = urea-ammonium nitrate (28-0-0), AMS = ammonium sulfate (21-0-0), NA = not applicable.
[a] Poast Plus allows Dash to replace POC or VOC.
[b] Current label: "Rainfall soon after application may decrease effectiveness."
[c] Some tank mixes allow POC or NIS—see the tank mix partner's label.
[d] Use only as a spot treatment. Do not use adjuvants with wiper applications of Roundup.

Soybean preharvest treatments

Roundup can be applied *preharvest* in soybeans after soybean pods have set and lost all green color. Allow a minimum of 7 days between application and soybean harvest. By air, Roundup may be applied at a rate of 1 quart per acre. Ground application at a higher rate is also allowed but is usually only feasible for spot treatment. Do not graze or harvest treated crop for livestock feed within 25 days of the last preharvest application. Do not treat soybeans grown for seed beans as there may be a reduction in germination or vigor.

Gramoxone Extra (paraquat) may be used for drying weeds in soybeans just before harvest. For indeterminate varieties (most of the varieties planted in Illinois), apply when 65 percent of the seed pods have reached a mature brown color or when seed moisture is 30 percent or less. For determinate varieties, apply when at least half of the leaves have dropped and the rest of the leaves are turning yellow.

The rate is 12.8 fluid ounces of Gramoxone Extra per acre. The total spray volume per acre is 2 to 5 gallons for aerial application and 20 to 40 gallons for ground application. Add 1 quart of nonionic surfactant per 100 gallons of spray. Do not pasture livestock within 15 days of treatment, and remove livestock from treated fields at least 30 days before slaughter. *Gramoxone Extra is a restricted-use pesticide.*

Problem perennial weeds

Perennials first appear as light infestations, but if left unattended they can become serious, causing reductions in yield, grain quality, and harvesting efficiency. Perennial weed problems are increasing in Illinois because of reduced competition from annuals and less tillage. Spreading perennials reproduce from vegetative propagules, which can be spread by chisel plows or field cultivators. For tillage to be beneficial,

Table 15.22. Corn Postemergence Herbicides: Perennial Broadleaf Weed Control Ratings

Herbicide	BWD	BMG	CTL	CDK	GCR	CMW	HDB	HMW	HNT	JAC	PKW	SSW	TCR
2,4-D pretassel	7	6	6	5	5	5	6	6	7	7	7	5	5
2,4-D preharvest	**8**	7	7	6	7	7	6	7	**8**	**8**	**8**	6	6
Banvel + 2,4-D	7+	6	7	7	6	6	7	6	7+	7	**8**	7	5
Banvel	**8**	5	**8**	**8**	7	7	7	7	**8**	**8**	**8**	7	5
Stinger	5	5	**9**	7	6	6	5	6	5	**9**	5	5	5
Accent	5	5	5	5	6	6	6	7	6	5	7	5	5
Beacon	6	5	7	6	6	6	6	6	**8**	**8**	7	5	6
Beacon + 2,4-D	7	5	7	6	6	7	7	7	**8**	7	7	5	6
Roundup[a]	**8**	5	**8**	7	**8**	**8**	**9**	7	**8**	7	**9**	**8**	7

BWD = field or hedge bindweed, BMG = bigroot morningglory (wild sweetpotato), CTL = Canada thistle, CDK = curly dock, GCR = groundcherry, CMW = common milkweed, HDB = hemp dogbane, HMW = honeyvine (climbing) milkweed, HNT = horsenettle, JAC = Jerusalem artichoke, PKW = pokeweed, SSW = swamp smartweed (devil's shoestring), TCR = trumpetcreeper. 9 = 85 to 95% control, 8 = 75 to 85%, 7 = 65 to 75%, 6 = 55 to 65%, 5 and below = insignificant control, + = control at the higher end of the range. Boldface indicates acceptable control.
[a] Use only as a spot treatment.

root fragments need to be left on the surface and exposed to either freezing or dessication. Repeated tillage or mowing can deplete root food reserves and make the plants more susceptible to chemical control. Control of spreading perennials often relies on a combination of tillage to weaken the plants and the use of translocated (systemic) herbicides.

Translocated herbicides to control perennial weeds

Translocated herbicides should be applied when "food" is moving to the root if control of perennials is to be effective. Early in the spring food moves up from root reserves to support vegetative growth, and herbicides will provide "top kill." For the majority of perennials, the most effective applications are at early bud to bloom stage or early in fall when the plants are replenishing food reserves in the roots. However, translocated herbicides should not be applied to corn or soybeans during their reproductive stages. Unfortunately, corn and soybeans are often in reproductive stages when most warm season perennials are in the bud to bloom stage. Translocated herbicides cleared for preharvest applications are 2,4-D in corn and Roundup in soybeans. Fallow or set-aside land or application following small grain harvest may offer better opportunities to work on warm season perennials. Since no control program is completely effective, adequate control may take several years.

Tables 15.22 and 15.23 list translocated herbicides for control or suppression of perennial weeds in corn and soybeans and give weed control ratings (Table 15.22) and crop stages and rates per acre (Table 15.23). See Table 15.24 for a detailed discussion of perennial weed control by individual species. Multiple low rate treatments, if allowed, are often more effective than single high rates. 2,4-D, Banvel, Stinger, Beacon, and Pursuit are translocated herbicides used in corn to control perennial broadleaf weeds. Accent and Beacon are used to control johnsongrass and quackgrass in corn.

2,4-D amine or LV ester can be applied with drop nozzles to corn over 8 inches tall up to tassel stage. The rate per acre of a 3.8 pounds a.e. per gallon formulation is 0.5 to 0.75 pint of ester or 1 to 1.5 pints of amine. **Weedone 638** (2.8 pounds a.e. per gallon of 2,4-D ester and acid) is used at 1 pint per acre on perennials. *Do not use LV ester if temperatures are expected to exceed 80°F the next few days following application.* Some 2,4-D labels allow a higher rate when used preharvest after the hard-dough or dent stage of corn. 2,4-D can also be used at higher rates on grassland or fallow ground, but allow 3 months after application before planting soybeans.

Banvel 4S can be applied at ½ pint when corn is 8 to 36 inches tall or up to 15 days before tassel emergence, whichever is first. A second application of Banvel can be made after two weeks, up to a maximum of 1.5 pints per season. Do not apply Banvel to corn over 24 inches tall if soybeans growing nearby are over 10 inches tall or have begun to bloom. Banvel + 2,4-D at 0.5 pint plus 0.25 pint, respectively, per acre can be applied after corn is 8 inches tall. Use drop nozzles to apply Banvel when tank-mixing with 2,4-D, when corn leaves prevent proper spray coverage, or when sensitive crops are growing nearby. Adhere closely to all label precautions to prevent injury to nontarget plants in the area. Do not cultivate corn for at least 1 week after application to allow herbicide translocation.

Banvel can be applied on fallow ground at 1 to 2 pints per acre to suppress perennials. Use 2 pints per

Table 15.23. Corn Stage and Application Rate for Perennial Broadleaf Weed Control

Herbicide	Corn stage	Product rate
2,4-D	Pretassel[a]	1 pt amine/acre or 0.5 pt ester/acre
2,4-D	Preharvest	2 to 3 pt amine/acre or 2 pt ester/acre
Banvel + 2,4-D	8 to 36 in.[a,b]	0.5 pt Banvel + 0.25 pt 2,4-D/acre
Banvel	≤36 in.[b]	1 pt/acre early, 0.5 pt/acre late
Stinger	≤24 in.	0.50 to 0.66 pt/acre
Accent	≤36 in.[c]	0.67 oz/acre
Beacon	Pretassel[d]	0.76 oz/acre
Beacon + 2,4-D	Pretassel[a]	0.38 oz + 1 pt/acre
Roundup	Pretassel	2% solution as a spot treatment

[a] Use drop nozzles with 2,4-D in corn over 8 in.
[b] 24 in. if soybeans are blooming or are over 10 in.
[c] Use drop nozzles with Accent in corn over 24 in. or with 6 leaf collars.
[d] Use drop nozzles with Beacon in corn over 20 in.

Table 15.24. Problem Perennial Weeds

Weed	Crop	Herbicide and per-acre rate	Remarks
Bindweed, field and hedge *(Convolvulus arvensis and Calystegia sepium)*	Field corn	2,4-D ester: ½ to ¾ pt Weedone 638: 1 pt 2,4-D amine: 1 to 1½ pt	See text. Use drop nozzles on corn over 8 in. tall. Some labels allow a higher rate as a preharvest treatment. For 2,4-D: if not 3.8 lb acid equivalent per gallon, use equivalent amount.
		Banvel: ½ to 1 pt	See text. Can use higher rate on fallow ground.
		Banvel: ½ pt + 2,4-D: ¼ pt	See text. Use drop nozzles.
		Laddok S-12: 2.33 pt	See text. Suppress 8- to 10-in. bindweed. 2,4-D will improve control. Apply before corn is 12 in. tall.
	Soybeans	Blazer: 1.5 pt or Reflex: 1 to 1¼ pt	Suppression.
	Corn/soybeans	Basagran: 2 to 3 pt	Suppression.
		Roundup spot treatment: 2% solution	See text. Apply before reproductive stage of crop.
Bigroot morning-glory (also called wild sweet potato) *(Ipomoea pandurata)*	Field corn	2,4-D ester: ½ to ¾ pt Weedone 638: 1 pt 2,4-D amine: 1 to 1½ pt	See text. For 2,4-D: if not 3.8 lb acid equivalent per gallon, use equivalent amount.
	Corn/soybeans	Roundup spot treatment: 2% solution	Treat actively growing weeds that are at or beyond the bloom stage. Repeat application will be required. See text.
Canada thistle *(Cirsium arvense)*	Field corn	2,4-D ester: ½ to ¾ pt Weedone 638: 1 pt 2,4-D amine: 1 to 1½ pt	See text. Apply as near to bud stage as possible. Use drop nozzles on corn over 8 in. tall. For 2,4-D: if not 3.8 lb acid equivalent per gallon, use equivalent amount.
		Banvel: ½ to 1 pt	See text.
		Banvel: ½ pt + 2,4-D: ¼ pt	See text. Use drop nozzles.
		Stinger: ⅓ to ⅔ pt	Apply when thistles are at least 4 in. in diameter or height, but before weed bud stage and before corn is 24 in. tall. Do not cultivate before application or for 14 to 20 days after.
		Laddok S-12: 2.33 pt	Suppress Canada thistle 8 to 10 in. tall. Apply before corn is 12 in. tall. Can be tank-mixed with Stinger.
		Buctril: 2EC 1.5 pt or Buctril Gel: 0.75 pt	Suppress thistles from 8 in. tall to the bud stage. Apply when corn is between the 4-leaf stage and prior to tassel emergence. Can be tank-mixed with Stinger.
		Beacon: 0.76 fl oz	Suppression. Apply when Canada thistle is 2 to 9 in. tall. Corn should be 4 to 20 in. tall to avoid injury.
	Soybeans	Cobra: 12.5 fl oz	Suppress thistle up to 6-leaf stage.
		Galaxy: 2 pt	Suppress thistle between 8 in. tall and the bud stage.
		Roundup: 33% solution for wiper application	Do not add surfactant in wiper applications. Weeds should be at least 6 in. taller than the crop. Better results are obtained if two applications are made in opposite directions.
	Corn/soybeans	Basagran: 2 pt	Suppression. Apply when thistles are between 8 in. tall and the bud stage. Reapply 2 pt 7 to 10 days later.
		Pursuit 2S: 4 fl oz Pursuit 70DG: 1.4 fl oz	Suppression. Apply to weeds 1 to 3 in. tall. Cultivation may help control. Use only on Pursuit-resistant or -tolerant field corn hybrids, and apply before corn exceeds the 8-leaf stage.
		Roundup: spot treatment 2% solution	See text. Apply on a spray-to-wet basis.

Table 15.24. Problem Perennial Weeds (cont.)

Weed	Crop	Herbicide and per-acre rate	Remarks
Common milkweed *(Asclepias syriaca)* and hemp dogbane *(Apocynum cannabinum)*	Field corn	2,4-D ester: ½ to ¾ pt Weedone 638: 1 pt 2,4-D amine: 1 to 1½ pt	Banvel or a mixture of Banvel plus 2,4-D is preferable to 2,4-D alone for common milkweed. For hemp dogbane, apply when weeds are in the bud to bloom stage. For 2,4-D: if not 3.8 lb acid equivalent per gallon, use equivalent amount.
		Banvel: ½ to 1 pt	See text.
		Banvel: ½ pt + 2,4-D: ¼ pt	See text. Use drop nozzles.
		Beacon: ⅜ oz + 2,4-D: ¾ pt	Suppress 1- to 3-in. common milkweed and 2- to 6-in. hemp dogbane.
		Beacon: ⅜ oz + Banvel: ½ pt	Suppress 2- to 6-in. hemp dogbane.
	Soybeans	Blazer: 1.5 pt	Suppression. Common milkweed only. See text.
		Cobra: 12.5 fl oz	Suppression. Common milkweed only. Apply to emerged, actively growing weeds up to the 6-leaf stage.
		Roundup 33% solution for wiper application	Do not add surfactant in this type of application. Weeds should be at least 6 in. taller than the crop. Better results are obtained if two applications are made in opposite directions.
		Synchrony STS: 0.85 oz	Suppress 2- to 6-in. common milkweed.
	Corn/soybeans	Roundup: spot treatment 2% solution	See text. Apply on a spray-to-wet basis.
Honeyvine milkweed (also called climbing milkweed) *(Ampelamus albidus)*	Field corn	2,4-D ester: ½ to ¾ pt Weedone 638: 1 pt 2,4-D amine: 1 to 1½ pt	See text. Use drop nozzles if corn is over 8 in. tall. For 2,4-D: if not 3.8 lb acid equivalent per gallon, use equivalent amount.
		Banvel: ½ to 1 pt	See text.
		Banvel: ½ pt + 2,4-D: ¼ pt	See text. Use drop nozzles.
		Beacon: ⅜ oz + 2,4-D: ¾ pt	Suppress 1- to 3-in. honeyvine milkweed.
Jerusalem artichoke *(Helianthus tuberosus)*	Field corn	2,4-D ester: ½ to ¾ pt Weedone 638: 1 pt 2,4-D amine: 1 to 1½ pt	See text. Use drop nozzles if corn is over 8 in. tall. For 2,4-D: if not 3.8 lb acid equivalent per gallon, use equivalent amount.
		Banvel or Clarity: ½ to 1 pt	See text. Use Clarity before corn is 8 in. tall.
		Banvel: ½ pt + 2,4-D: ¼ pt	See text. Use drop nozzles on corn over 8 in. tall.
		Stinger: ¼ to ½ pt	Apply up to the 5-leaf weed stage. Apply to corn from emergence to 24 in.
		Beacon: ¾ oz	Apply to 1- to 4-in. Jerusalem artichoke plants when corn is 4 to 20 in. tall.
	Soybeans	Classic: 0.75 fl oz or Synchrony STS: 0.85 oz	Apply to emerged weeds less than 8-leaf or 6 to 8 in., whichever is first. May reapply Classic after 14 to 21 days (to a maximum of 1.5 oz per season), but cultivation after 14 days may replace retreatment.
	Corn/soybeans	Pursuit 2S: 4 fl oz Pursuit 70DG: 1.4 fl oz	Apply to weeds that are 8-leaf or 6 in., whichever is first. Cultivation may help control. Use only on Pursuit-resistant or -tolerant field corn hybrids, and apply before corn exceeds the 8-leaf stage.
		Roundup: spot treatment 2% solution	See text.

Table 15.24. Problem Perennial Weeds (cont.)

Weed	Crop	Herbicide and per-acre rate	Remarks
Swamp smartweed *(Polygonum coccineum)*	Field corn	Banvel: ½ to 1 pt	See text.
		Banvel: ½ pt + 2,4-D: ¼ pt	See text. Use drop nozzles.
		Stinger: ¼ to ½ pt	Suppression. Apply to weeds in the 2- to 3-leaf stage. Do not apply after corn is 24 in. tall.
	Corn/soybeans	Roundup: spot treatment 2% solution	See text.
Yellow nutsedge *(Cyperus esculentus)*	Field corn	Beacon: ¾ oz	Suppression. Apply to actively growing 1- to 4-inch weeds. Not effective when weeds are subject to drought, cold, or other stress.
		Laddok S-12: 2.33 pt	Suppress 1- to 4-in. nutsedge. Apply before corn is 12 in. tall.
		Several soil-applied corn herbicides have activity on yellow nutsedge. See Table 15.07 for ratings.	
	Soybeans	Classic: 0.5 to 0.75 oz or Synchrony STS: 0.85 oz	Apply to nutsedge at the 2- to 4-in. stage: adjust rate for height. May reapply Classic after 14 to 21 days (to a maximum of 1.5 oz per season), but after 14 days cultivation may replace retreatment.
		Galaxy: 2 pints	Apply when nutsedge is less than 6 to 8 in. tall. A repeat of Basagran may be needed after a Galaxy application.
		Several soil-applied soybean herbicides have activity on yellow nutsedge. See Table 15.13 for ratings.	
	Corn/soybeans	Pursuit 2S: 4 fl oz or Pursuit 70DG: 1.4 fl oz	Suppression. Apply to corn only if Pursuit-resistant or -tolerant hybrids. Apply to 1- to 3-in. weeds before corn is at 8-leaf stage.
		Basagran: 1.5 to 2.0 pt	Apply to 6- to 8-in. nutsedge. A second application 10 days later will improve control.
Quackgrass *(Elytrigia repens)*	Field corn	Accent: ⅔ oz (1 packet per 4 acres)	Apply to 2- to 4-in. tall quackgrass, or apply up to 1⅓ oz (in split application) on quackgrass up to 6 in. tall. See label for restrictions and additives.
		Beacon: ¾ oz (1 packet per 2 acres)	Apply to quackgrass when 4 to 8 in. tall. Control of this species is not immediate, and symptoms may take several days to develop. See label for restrictions and additives.
		Eradicane: 6.7E 7.33 pt/acre	A tank mix with atrazine will improve control.
	Soybeans	Assure II: 10 fl oz	Apply when quackgrass is 6 to 10 in. tall. For regrowth apply 7 fl oz/acre when quackgrass is 4 to 8 in. tall.
		Fusilade DX: 12 fl oz	Apply to 6- to 10-in. quackgrass. For regrowth, apply 8 fl oz to quackgrass up to 10 in. tall.
		Poast Plus: 36 fl oz	Apply to quackgrass 6 to 8 in. tall and re-treat at 24 fl oz for regrowth 6 to 8 in. tall.
		Select: 8 fl oz	Apply to quackgrass 4 to 8 in. tall and re-treat regrowth at the same rate and size if needed.
	Corn/soybeans	Roundup: 1 to 2 qt	Apply prior to spring tillage or after harvest in the fall. Do not till for 3 days before or after application. Weeds should be actively growing and greater than 8 in. tall.
Johnsongrass *(Sorghum halepense)*	Field corn	Accent: ⅔ oz (1 packet per 4 acres)	Apply to seedling johnsongrass when 4 to 12 in. tall and rhizome johnsongrass when 8 to 16 in. tall. See label for restrictions and additives.
		Beacon: ¾ oz (1 packet per 2 acres) as a single or split application	Apply to seedling johnsongrass when 4 to 12 in. tall and rhizome johnsongrass when 8 to 16 in. tall. See label for restrictions and additives.

Table 15.24. Problem Perennial Weeds (cont.)

Weed	Crop	Herbicide and per-acre rate	Remarks
Johnsongrass (cont.)	Soybeans	Assure II: 10 fl oz	Apply to johnsongrass when 10 to 24 in. tall. Apply additional 7 fl oz to regrowth when 6 to 10 in. tall if needed.
		Poast Plus: 24 fl oz	Apply to johnsongrass 15 to 25 in. tall. Treat 6- to 12-in. regrowth with same rate.
		Select: 8 fl oz	Apply to johnsongrass 12 to 24 in. tall. Apply 6 fl oz/acre to 6- to 10-in. regrowth if needed.
		Fusilade DX: 12 fl oz	Apply to 8- to 18-in. johnsongrass. Re-treat 6- to 12-in. regrowth at 8 fl oz/acre.
		Roundup: 33% solution for wiper application	Can also be used as a spot treatment. See text.
Wirestem muhly *(Muhlenbergia frondosa)*	Soybeans	Assure II: 8 fl oz	Apply when wirestem muhly is 4 to 8 inches tall. For 4- to 8-in. regrowth, apply 7 fl oz/acre.
		Fusilade DX: 12 fl oz	Apply to 4- to 12-inch wirestem muhly. Apply to regrowth at the same size and rate.
		Poast Plus 30 fl oz/acre	Apply to wirestem muhly up to 6 in. tall. Re-treat at same rate and size for regrowth.
		Select 8 fl oz	Apply when wirestem muhly is 4 to 8 in. tall. Regrowth may be treated at the same height with the same rate.

[a] a.e. = acid equivalent. If not 3.8 lb/gal, use equivalent amount.

acre to control curly dock, hemp dogbane, and Canada thistle and 4 pints per acre to control Jerusalem artichoke, field or hedge bindweed, horsenettle, swamp smartweed, and trumpetcreeper. Upright perennials should be 8 inches or taller, and vining perennials should be at or beyond the full bloom stage. Corn or soybeans may be planted the spring after applications made the previous year. Soybean injury may occur if less than 30 days per pint per acre of Banvel has elapsed. Do not count days when the ground is frozen.

Stinger is used in corn up to 24 inches tall at 0.25 to 0.5 pint per acre to control five-leaf Jerusalem artichoke and at 0.5 to 0.67 pint per acre to control 6-inch to bud-stage Canada thistle. Do not cultivate for 14 to 20 days after application to allow herbicide translocation.

Beacon or Accent controls quackgrass and johnsongrass in corn. See Table 15.24 for rates and weed heights. Beacon alone can be applied over the top of corn up to 20 inches tall to control or suppress 2- to 9-inch Canada thistle or horsenettle and 1- to 4-inch Jerusalem artichoke. A tank mix of 0.38 ounce per acre of Beacon with 0.5 pint Banvel or with 0.5 to 0.75 pint 2,4-D will help suppress 2- to 6-inch hemp dogbane or pokeweed and 1- to 3-inch poison ivy. The Beacon + 2,4-D tank mix also suppresses 1- to 3-inch honeyvine or common milkweed. Use crop oil concentrate or nonionic surfactant (NIS) with Beacon alone, but only NIS in tank mixes with 2,4-D or Banvel. Use drop nozzles with 2,4-D.

Pursuit used in soybeans or imidazolinone-resistant or -tolerant (IMI) corn controls or suppresses 6- to 10-inch Jerusalem artichoke, 1- to 3-inch Canada thistle, and 1- to 3-inch yellow nutsedge. **Classic** used at 0.75 ounce per acre postemergence in soybeans controls or suppresses 2- to 8-inch Jerusalem artichoke, 2- to 4-inch Canada thistle, or 2- to 4-inch yellow nutsedge. **Synchrony STS,** used only in sulfonylurea-tolerant (STS) soybeans, controls or suppresses 2- to 6-inch common milkweed or Jerusalem artichoke, 2- to 4-inch Canada thistle, and 2- to 3-inch yellow nutsedge.

Assure II, Fusilade DX, Poast Plus, and Select control johnsongrass, quackgrass, and wirestem muhly when used postemergence in soybeans. See Table 15.19 or Table 15.24 for rates and weed heights. The new Fusion label no longer covers quackgrass and wirestem muhly control.

Roundup can be applied with wiper applicators to control perennials if soybeans are at least 6 inches shorter than the weeds to allow selective applications. Two applications made in opposite directions provide better weed coverage. Mix 1 gallon of Roundup with 2 gallons of water. Do not add adjuvants. Do not cultivate for 5 days after application.

Roundup can be used as a spot treatment to control perennials in corn, soybeans, and grain sorghum up to the reproductive stages of the crops. "Bean buggies" are often used in soybeans for spot treatment. Apply a 2 percent solution (3 fluid ounces per 1 gallon of water) on a spray-to-wet (no runoff) basis, making sure the spray coverage is uniform and complete. If complete coverage cannot be obtained, use a 5 percent solution. Roundup can be used as a preharvest treatment in soybeans to control or suppress many perennials. See the earlier "Soybean Preharvest Treatments" section. Roundup can also be used at higher

rates on fallow ground to control perennial broadleaf weeds and grass sods.

Contact herbicides to suppress perennial weeds

Several contact postemergence herbicides used in corn and soybeans suppress certain perennial weeds by burning off top growth. This may reduce competition with the crop, but it will not prevent regrowth from plant roots as contact herbicides translocate very little. However, when selecting a contact herbicide to control annual weeds, you may want to select one that suppresses problem perennials.

Buctril and Laddok are contact herbicides used in corn. **Buctril** at 1.5 pints per acre will suppress 8-inch to bud-stage Canada thistle in corn. A tank mix with 0.25 to 0.5 pint of Banvel per acre improves suppression of Canada thistle and field bindweed, while a tank mix with 0.5 pint of Stinger per acre will control Canada thistle. **Laddok S-12** at 2.33 pints per acre suppresses 8-inch to bud-stage Canada thistle, 1- to 4-inch tall yellow nutsedge, and 8- to 10-inch long field bindweed. Add crop oil concentrate (COC) or Dash. Laddok plus 0.33 pint of Stinger per acre will control Canada thistle. Laddok S-12 at 1.66 pints per acre plus 0.25 pint of 2,4-D LV ester (4 pounds per gallon) applied before the fifth leaf of corn improves control of field bindweed and swamp smartweed. *Do not apply Laddok after corn is 12 inches tall.*

Basagran, Blazer, Cobra, and Reflex are contact herbicides used in soybeans. **Basagran** applied at 1.5 to 2 pints per acre plus COC controls 8-inch Canada thistle and 6- to 8-inch yellow nutsedge. A second application or cultivation 7 to 10 days later will improve control. Basagran applied at 2 to 3 pints per acre suppresses up to 10-inch tall field or hedge bindweed. **Blazer** used at 1.5 pints per acre plus 2 to 4 pints of nonionic surfactant (NIS) per 100 gallons of spray suppresses field bindweed, common milkweed, and trumpetcreeper.

Cobra at 12.5 fluid ounces plus 1 quart of COC per acre suppresses up to six-leaf Canada thistle, common milkweed, bigroot morningglory (wild sweetpotato), swamp smartweed, and trumpetcreeper. **Reflex** suppresses field and hedge bindweed as well as honeyvine milkweed. Use 1.0 pint per acre north of Interstate 70 and 1.25 pints south of Interstate 70. Add either 1 to 2 pints of COC or 0.5 to 1 pint of NIS per 25 gallons of spray mix.

Chapter 16.

1995 Weed Control for Small Grains, Pastures, and Forages

Good weed control is necessary for maximum production of high-quality small grains, pastures, and forages in Illinois. When properly established, these crops can usually compete effectively with weeds, so the need for herbicide applications is minimized. However, weeds can sometimes become significant problems and warrant control. For example, wild garlic is considered the worst weed problem in wheat in southern Illinois. Because its life cycle is similar to that of winter wheat, wild garlic can establish itself with the wheat, grow to maturity, and produce large quantities of aerial bulblets by wheat-harvest time. Economic considerations often make it necessary to control wild garlic in winter wheat to minimize dockage.

In pastures, woody and herbaceous perennials can become troublesome. Annual grasses and broadleaf weeds such as chickweed and henbit may cause problems in hay crops. Through proper management, many of these weed problems can be controlled effectively.

Several herbicide labels carry the following groundwater warnings under either the environmental hazard or the groundwater advisory section: "X is a chemical that can travel (seep or leach) through soil and enter groundwater that may be used as drinking water. X has been found in groundwater as a result of its use as a herbicide. Users of this product are advised not to apply X where the soils are very permeable (that is, well-drained soils such as loamy sands) and the water table is close to the surface." Table 16.01 lists herbicides that carry this warning. A few labels also warn against contamination of surface water.

Small grains

Good weed control is critical for maximum production of high-quality small grains. Often, problems with weeds can be dealt with before the crop is established. For example, some broadleaf weeds can be controlled effectively in the late fall with **2,4-D; Banvel** (dicamba); or with **Roundup** (glyphosate) after corn or soybean harvest, if seeding is not too late.

Tillage helps control weeds. Although generally limited to preplant or postharvest operations, tillage can destroy many annual weeds and help suppress certain perennials. Good cultural practices such as proper seeding rate, optimum soil fertility, and timely planting help to ensure the establishment of an excellent stand and a crop that is better able to compete with weeds.

Winter annual grasses such as downy brome and cheat are very competitive in winter wheat. Illinois wheat producers are often limited to preplant tillage operations for control of these species, as few herbicides have label clearances for annual grass control in winter wheat. If there is a severe infestation of downy brome or cheat, planting an alternative crop or spring crop may be best for that field.

A decision to use postemergence herbicides for broadleaf weed control in small grains should be based on several considerations:

1. *Nature of the weed problem.* Identify the species present and consider the severity of the infestation. Also note the size of the weeds. Weeds are usually best controlled while small.

2. *Stage of the crop.* Most herbicides are applied after full tiller until the boot stage. Do not apply herbicides from the boot stage to the hard-dough stage of small grains (see Figure 16.01 for a description of growth stages of small grains).

3. *Herbicide activity.* Determine crop tolerance and weed susceptibility to herbicides by referring to

Table 16.01. Herbicides, Formulations, and Special Statements

Trade name	Common name	Formulation	Restricted use	Groundwater advisory	Key word
Ally 60 DF	metsulfuron	60%	—	—	Caution
Balan 1.5E	benefin	1.5 lb/gal	—	—	Warning
Banvel	dicamba	4 lb a.e./gal[a]	—	—	Warning
Buctril	bromoxynil	2 lb/gal, 4 lb/gal (gel)	—	—	Warning
Butyrac 200	2,4-DB	2 lb a.e./gal	—	Yes	**Danger**[b]
Crossbow	2,4-D + triclopyr	2 + 1 lb a.e./gal	—	Yes	Caution
Eptam 7E, 10G	EPTC	7 lb/gal, 10%	—	—	Caution
Fusilade DX	fluazifop	2 lb a.e./gal	—	—	Caution
Gramoxone Extra	paraquat	2.5 lb/gal	Yes	—	**Danger**[b]
Harmony Extra 75DF	thifensulfuron + tribenuron	75%	—	—	Caution
Kerb 50W	pronamide	50%	Yes	—	Caution
Lexone 75DF	metribuzin	75%	—	Yes	Caution
MCPA	MCPA	several	—	—	Warning
Poast Plus	sethoxydim	1 lb/gal	—	—	Caution
Prowl	pendimethalin	3.3 lb/gal	—	—	Caution
Roundup	glyphosate	3 lb a.e./gal	—	—	Warning
Sencor 4L	metribuzin	4 lb/gal	—	Yes	Caution
Sencor 75DF	metribuzin	75%	—	Yes	Caution
Sinbar 80W	terbacil	80%	—	—	Caution
Spike 20P	tebuthiuron	20%	—	Yes	Caution
Stinger	clopyralid	3 lb a.e./gal	—	Yes	Caution
Treflan	trifluralin	4 lb/gal, 5 lb/gal, 10G	—	—	Warning
Velpar L	hexazinone	2 lb/gal	—	—	**Danger**[b]
Weedmaster	dicamba + 2,4-D	1 + 2.87 lb/gal	—	—	Caution
2,4-D amine	2,4-D	3.8 lb a.e./gal	—	—	**Danger**[b]
2,4-D ester	2,4-D	3.8 lb a.e./gal	—	—	Caution

[a] a.e. = acid equivalent for these herbicides. All others are active ingredient (a.i.) formulations.
[b] Danger: Check label for safety equipment and precautions.

Table 16.02 and Table 16.03. The lower rates in Table 16.03 are for more easily controlled weeds and the higher rates for the more difficult-to-control species. Tank mixes may broaden the weed spectrum and thereby improve control; check the herbicide label for registered combinations.

4. *Presence of a legume underseeding.* Usually 2,4-D ester formulations and certain other herbicides listed in Table 16.03 should not be applied because they may damage the legume underseeding.

5. *Economic justification.* Consider the treatment cost in terms of potential benefits, such as the value of increased yield, improved quality of grain, and ease of harvesting the crop.

Table 16.03 outlines current suggestions for weed-control options in wheat and oats, the two small grains most commonly grown in Illinois. Please refer to Table 16.04 for grazing restriction information concerning herbicides used in small grains. Always consult the herbicide label for specific information about the use of a given product.

For annual broadleaf weeds, postemergence herbicides such as **2,4-D; MCPA; Banvel;** and **Buctril** (bromoxynil) can provide good control of susceptible species (Table 16.02). Herbicides must be applied during certain growth stages of the crop to avoid crop injury and for optimum weed control. Refer to Figure 16.01 for a description of the growth stages of small grains.

Some perennial broadleaf weeds may not be controlled satisfactorily with the low herbicide rates used in small grains, and higher rates are not advisable because they can cause serious injury to crops. To control perennial weeds, translocated herbicides such as **2,4-D; Banvel;** or **Roundup;** in combination with tillage after small grain harvest or after soybean harvest but before establishing small grains, may be the best approach.

Stinger (clopyralid) may be used to control broadleaf weeds in wheat, oats, and barley. Stinger controls Canada thistle as well as a number of annual broadleaf weeds (Table 16.02).

Wild garlic continues to be a serious weed problem in winter wheat. **Harmony Extra** (thifensulfuron + tribenuron), applied in the spring at 0.3 to 0.6 ounce of 75DF per acre, effectively controls wild garlic aerial bulblets and some underground bulbs as well. Harmony Extra also helps control chickweed, henbit, common lambsquarters, smartweed, and several species of mustard. See Tables 16.02 and 16.03 for additional information on controlling weeds in small grains.

Grass pastures

Unless properly managed, broadleaf weeds can become a serious problem in grass pastures. They can compete directly with forage grasses and reduce the nutritional value and longevity of the pasture. Certain species, such as white snakeroot and poison hemlock, are also poisonous to livestock and may require special consideration.

Perennial weeds are of great concern in pasture

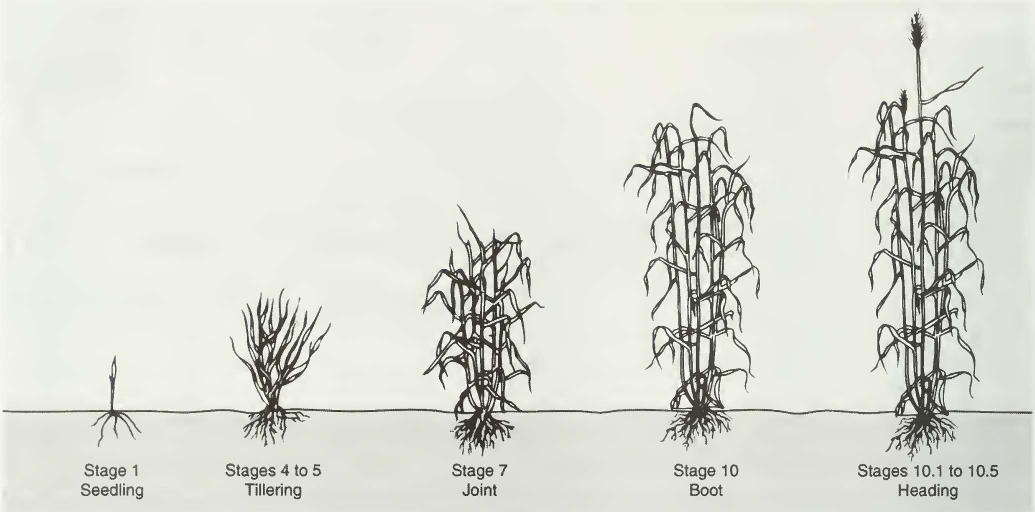


Figure 16.01. Growth stages of small grains.

Seedling

Stage 1. The coleoptile, a protective sheath that surrounds the shoot, emerges. The first leaf emerges through the coleoptile, and other leaves follow in succession from within the sheath of the previously emerging leaf.

Tillering

Stages 2 to 3. Tillers (shoots) emerge on opposite sides of the plant from buds in the axils of the first and second leaves. The next tillers may arise from the first shoot at a point above the first and second tillers or from the tillers themselves. This process is repeated until a plant has several shoots.

Stages 4 to 5. The leaf sheaths lengthen, giving the appearance of a stem. The true stems in both the main shoot and the tillers are short and concealed within the leaf sheaths.

Jointing

Stage 6. The stems and leaf sheaths begin to elongate rapidly, and the first node (joint) of the stem is visible at the base of the shoot.

Stage 7. The second node (joint) of the stem is visible. The next-to-last leaf is emerging from within the sheath of the previous leaf but is barely visible.

Stage 8. The last leaf, the "flag leaf," is visible but still rolled.

Stage 9: Preboot stage. The ligule of the flag leaf is visible. The head begins to enlarge within the sheath.

Stage 10: Boot stage. The sheath of the flag leaf is completely emerged and distended because of the enlarging but not yet visible head.

Heading

Stages 10.1 to 10.5. Heads of the main stem usually emerge first, followed in turn by heads of the tillers in order of their development. Heading continues until all heads are out of their sheaths. The uppermost internode continues to lengthen until the head is raised several inches above the uppermost leaf sheath.

Flowering

Stages 10.5.1 to 10.5.3. Flowering progresses in order of head emergence. Unpollinated flowers result in no kernels.

Stage 10.5.4: Premilk stage. Flowering is complete. The inner fluid is abundant and clear in the developing kernels of the flowers pollinated first.

Ripening

Stage 11.1: Milk stage. Kernel fluid is milky white because of accumulating starch.

Stage 11.2: Dough stage. Kernel contents are soft and dry (doughy) as starch accumulation continues. The plant leaves and stems are yellow.

Stage 11.3. The kernel is hard, difficult to divide with the thumbnail.

Stage 11.4. The kernel is ripe for cutting and will fragment when crushed. The plant is dry and brittle.

Table 16.02. Effectiveness of Herbicides on Weeds in Small Grains

This table compares the relative effectiveness of herbicides on individual weeds. Ratings are based on labeled application rate and weed size or growth stage. Performance may vary due to weather and soil conditions or other variables.

Weed	Susceptibility to herbicide					
	2,4-D	MCPA	Banvel	Buctril	Harmony Extra	Stinger
Winter annual						
Buckwheat, wild	5	8	10	9	8	8
Chickweed, common	5	5	6	6	9	0
Henbit	5	5	6	8	9	0
Horseweed (marestail)	8	8	10	6	7	9
Lettuce, prickly	10	9	8	6	8	9
Mustard spp., annual	10	10	6	9	9	0
Pennycress, field	10	10	6	8	9	0
Shepherdspurse	10	10	8	8	9	0
Summer annual						
Lambsquarters, common	10	10	10	10	8	0
Pigweed spp.	10	10	10	7+	9	0
Ragweed, common	10	9	10	9	0	9
Ragweed, giant	10	9	10	8	0	10
Smartweed, Pennsylvania	6	7	9	9	9	7
Perennial						
Dandelion	9	8	8	0	6	9
Garlic, wild						
Aerial bulblets	6*	5	5	0	9	0
Underground bulbs	0	0	0	0	5	0
Thistle, Canada	7	7	8	6	7	9

10 = 95 to 100%, 9 = 85 to 95%, 8 = 75 to 85%, 7 = 65 to 75%, 6 = 55 to 65%, 5 = 45 to 55%, 0 = less than 45% control or not labeled, + = control at the higher end of the range.
* 2,4-D ester at maximum use rate.

Table 16.03. Weed Control in Small Grains

Herbicide	Broadcast rate/acre	Remarks (see Table 16.04 for grazing restrictions)
Oats and wheat with legume underseeding		
2,4-D amine (3.8 lb a.e.)	½ to 1½ pt	Winter wheat more tolerant than oats. Apply in spring after full tiller but before boot stage. Do not treat in fall. Use lower rate if underseeded with legume. Some legume damage may occur. May be used as preharvest treatment at 1 to 2 pt per acre during hard-dough stage.
MCPA amine	¼ to 3 pt	Less likely than 2,4-D to damage oats and legume underseeding. Apply from 3-leaf stage to boot stage. Rate varies with crop and weed size and presence of legume underseeding.
Buctril 2E Buctril 4 Gel	1 to 2 pt ½ to ¾ pt	Apply Buctril alone to fall-seeded small grains in the fall or spring before the boot stage. Weeds are best controlled before the 3- to 4-leaf stage. Buctril may be applied at 1 to 1½ pt per acre to small grains underseeded with alfalfa.
Oats and wheat without legume underseeding		
Banvel, 4 lb a.e.	4 fl oz	*Do not use with legume underseeding.* In fall-seeded wheat, apply before jointing stage. In spring-seeded oats, apply before oats exceed 5-leaf stage.
Stinger, 3 lb a.e.	¼ to ⅓ pt	*Do not use with legume underseeding.* Apply to small grains from the 3-leaf stage up to the early boot stage. For control of Canada thistle, ⅓ pt per acre should be used. For control of additional weeds, Buctril, Banvel, Harmony Extra, MCPA, or 2,4-D may be tank-mixed with Stinger.
Harmony Extra 75DF	0.3 to 0.6 oz	*Do not use with legume underseeding.* Make applications to wheat after the crop is in the 2-leaf stage, but before the flag leaf is visible. For spring oats, make applications after the crop is in the 3- to 5-leaf stage but before jointing. The use rate for spring oats is 0.3 to 0.4 oz per acre. Wild garlic should be less than 12 in. tall, with 2 to 4 in. of new growth. Annual broadleaf weeds should be past the cotyledon stage, actively growing, and less than 4 in. tall or across. Nonionic surfactant at 0.25% volume per volume (v/v) should be included in the spray mixture. When liquid fertilizer is used as the carrier, use 1/16-¼% v/v surfactant. Temporary stunting and yellowing may occur when Harmony Extra is applied using liquid fertilizer solution as the carrier. These symptoms will be intensified with the addition of surfactant. Without surfactant addition, wild garlic control may be erratic. Do not plant any crop other than wheat or oats within 60 days after application.
Wheat only		
2,4-D ester, 3.8 lb a.e.	½ to ¾ pt	*Do not use with legume underseeding.* Apply in spring after full tiller but before boot stage. For preharvest treatment, apply 1 to 2 pt per acre during hard-dough stage. For control of wild garlic or wild onion, apply 1 to 2 pt in the spring when wheat is 4 to 8 in. high, after tillering but before jointing; these rates may injure the crop and suppress only wild garlic.

Table 16.04. Small Grain Herbicides and Livestock Use

Herbicide name				Days after treatment before			
				Graze green			
Trade	Common	Crops	Applied	Beef	Dairy	Feed straw	Withdraw for meat
Banvel	dicamba	wheat, oats, barley	Prejoint	No	No	Yes	0
Buctril	bromoxynil	wheat, oats, rye, barley, triticale	Preboot	30	30	30	30
Harmony Extra	2:1 mixture of thifensulfuron + tribenuron	wheat, barley spring oats	Before flagleaf Prejoint	No	No	Yes	0
Many	2,4-D	wheat, oats, rye, barley	Preboot	0	14	0	14
Many	2,4-D–late	wheat, oats, rye, barley	Before harvest	No	No	No	. . .*
Many	MCPA	wheat, oats, rye, barley	Prejoint	0	7	0	7
Stinger	clopyralid	wheat, oats, barley	Preboot	0	7	No	7

* No withdrawal information available.

management. They can exist for many years, reproducing from both seed and underground parent rootstocks. Occasional mowing or grazing helps control certain annual weeds, but perennials can grow back from underground root reserves unless long-term control strategies are implemented.

Certain biennials can also flourish in grass pastures. The first year they exist as a prostrate rosette, so that even close mowing does little to control their growth. The second year, biennials produce a seedstalk and a deep taproot. If these weeds are grazed or mowed at this stage, root reserves can enable the plant to grow again, thereby increasing its chance of surviving to maturity.

In general, the use of good cultural practices such as maintaining optimum soil fertility, rotational grazing, and periodic mowing can help keep grass pastures in good condition and more competitive with weeds. Where broadleaf weeds become troublesome, however, **2,4-D; Banvel; Weedmaster** (dicamba + 2,4-D); or **Stinger** may be used. **Roundup** may also be used as a spot treatment, and **Crossbow** (2,4-D plus triclopyr) or **Ally** (metsulfuron methyl) are labeled for control of broadleaf and woody plant species in grass pastures. **Spike 20P** (tebuthiuron) may also be used in grass pastures for brush and woody plant control (see Tables 16.05 and 16.06 for additional information).

Proper identification of target weed species is important. As shown in Table 16.05, weeds vary in their susceptibility to herbicides. Timing of herbicide application may also affect the degree of weed control. Annuals and biennials are most easily controlled while young and relatively small. A fall or early spring herbicide application works best if biennials or winter annuals are the main weed problem. Summer annuals are most easily controlled in the spring or early summer. Apply translocated herbicides to control established perennials when the weeds are in the bud to bloom stage. Perennials are most susceptible at this reproductive stage because translocated herbicides can move downward with food reserves to the roots, thus killing the entire plant.

For control of woody brush, apply **2,4-D, Banvel,** or **Crossbow** when the plants are fully leafed and actively growing. Where regrowth occurs, a second treatment may be needed in the fall. During the dormant season, oil-soluble formulations of **2,4-D, Banvel,** or **Crossbow** may be applied in fuel oil to the trunk. **Spike** controls many woody perennials and should be applied to the soil in the spring. Spike requires rainfall to move it into the root zone of target species. **Ally** as a spot treatment controls multiflora rose, Canada thistle, and blackberry (*Rubus spp.*) and controls several annual broadleaf weeds when applied as a broadcast treatment at the lower rate range.

The weed control options in grass pastures are shown in Table 16.06. Refer to Table 16.07 for information concerning grazing restrictions for herbicides used in grass pastures. Be cautious with any pesticide, and always consult the herbicide label for specific information about the use of a given product.

Roundup may be used as a preharvest treatment in wheat for control of annual and certain perennial weed species. Applications should be made only after the hard-dough stage of the grain (30% or less grain moisture) and at least 7 days prior to harvest. Roundup may be applied at a maximum rate of 1 quart per acre using ground or aerial application equipment. It is not recommended that wheat being grown for seed be treated with Roundup because a reduction in germination or vigor may occur.

Forage legumes

Weed control is important in managing forage legumes. Weeds can reduce the vigor of legume stands, reducing yield and forage quality. Good management begins with weed control that prevents weeds from becoming serious problems.

Establishment

To minimize problems, prepare the seedbed properly so that it is firm and weed-free. Select an appropriate legume variety. If you use high-quality seed and follow the recommendations for liming and fertility, the legume crop may compete well with many weeds and reduce the need for herbicides.

Table 16.05. Effectiveness of Herbicides on Weeds in Grass Pastures

This table compares the relative effectiveness of herbicides on individual weeds. Ratings are based on labeled application rate and weed size or growth stage. Performance may vary due to weather and soil conditions or other variables.

	Susceptibility to herbicide					
Weed	Ally	2,4-D	Banvel	Crossbow	Stinger	Roundup[a]
Winter annual						
Horseweed (marestail)	9	9	10	10	9	10
Pennycress, field	0	10	8	9	0	10
Summer annual						
Ragweed, common	0	10	10	10	9	10
Ragweed, giant	0	10	10	10	10	10
Biennial						
Burdock, common	0	10	10	10	8	9
Hemlock, poison	0	9	10	10	0	9
Thistle, bull	0	10	10	10	9	10
Thistle, musk	9	10	9	9	9	10
Perennial[b]						
Daisy, oxeye	0	8	10	10	9	9
Dandelion	0	10	8	10	9	8
Dock, curly	0	7	10	10	8	9
Goldenrod spp.	0	8	9	8	0	10
Hemlock, spotted water	0	9	10	10	0	9
Ironweed	0	8	10	9	0	10
Milkweed, common	0	6	8	8	0	8
Nettle, stinging	0	9	9	9	0	9
Plantain spp.	0	10	8	10	0	9
Rose, multiflora[c]	9	8	9	9	0	9
Snakeroot, white	0	8	9	9	0	8
Sorrel, red	0	5	10	10	6	8
Sowthistle, perennial	0	8	9	10	7	9
Thistle, Canada	9	8	9	9	10	8

10 = 95 to 100%, 9 = 85 to 95%, 8 = 75 to 85%, 7 = 65 to 75%, 6 = 55 to 65%, 5 = 45 to 55%, 0 = less than 45% control or not labeled.
[a] Spot treatment only.
[b] Perennial weeds may require more than one application.
[c] Spike is also an effective herbicide for multiflora rose control (weed susceptibility = 10).

In fields where companion crops such as oats are used to reduce weed competition, seed the small grain at half the rate for grain production to ensure that the legumes will become established with minimum stress. If the legume is seeded without a companion crop (direct-seeded), the use of an appropriate herbicide is suggested.

Preplant-Incorporated herbicides

Balan (benefin) and **Eptam** (EPTC) are registered for preplant incorporation for legumes that are not seeded with grass or small-grain companion crops. These herbicides will control most annual grasses and some broadleaf weeds. In fall plantings, the weeds controlled include winter annuals such as downy brome and cheat. In spring legume plantings, the summer annual weeds controlled include foxtails, pigweeds, lambsquarters, crabgrass, and fall panicum. **Eptam** can help suppress johnsongrass, quackgrass, yellow nutsedge, and shattercane, in addition to controlling many annual grasses and some broadleaf weeds. Neither herbicide will effectively control mustards, smartweed, or established perennials.

Balan and **Eptam** *must* be thoroughly incorporated soon after application to avoid herbicide loss. They should be applied shortly before the legume is seeded so they remain effective as long as possible into the growing season.

Weeds that emerge during crop establishment should be evaluated for their potential to become problems. If they do not reduce the nutritional value of the forage or if they can be controlled by mowing, they should not be the primary focus of a postemergence herbicide application. For example, winter annual weeds do not compete vigorously with the crop after the first spring cutting. Unless they are unusually dense or production of weed seed becomes a concern, these weeds may not be a significant problem. Some weeds such as dandelions are palatable and may not need to be controlled if the overall legume stand is dense and healthy, but undesirable weeds must be controlled early to prevent their establishment.

Postemergence herbicides

Poast Plus (sethoxydim) may be applied to seedling alfalfa for control of annual and some perennial grass weeds after weed emergence. Grasses are more easily controlled when small. **Butyrac** (2,4-DB) controls many broadleaf weeds and may be applied postemergence in many seedling forage legumes. **Buctril** (bromoxynil)

Table 16.06. **Broadleaf Weed Control in Grass Pastures**

Herbicide	Rate/acre	Remarks (see Table 16.07 for grazing restrictions)
2,4-D, 3.8 lb a.e. (amine or low-volatile ester)	2 to 4 pt	Broadleaf weeds should be actively growing. Higher rates may be needed for less susceptible weeds and some perennials. Spray bull or musk thistles in the rosette stage (spring or fall) while they are actively growing. Spray perennials such as Canada thistle in the bud stage or the fall regrowth stage. Spray susceptible woody species in spring when leaves are fully expanded. Do not apply to newly seeded areas or to grass when it is in boot to milk stage. Be cautious of spray drift.
Ally 60 DF	1/10 to 3/10 oz	Apply in the spring or early summer before annual broadleaf weeds are 4 in. tall. As a spot application for control of multiflora rose, blackberry, or Canada thistle, apply Ally at 1 oz per 100 gal of water and spray foliage to runoff. Include a nonionic surfactant of at least 80% active ingredient at 1 pt to 1 qt per 100 gal spray solution (1/8 to 1/4% v/v). Bluegrass, bromegrass, orchardgrass, timothy, and native grasses such as bluestem and grama have demonstrated good tolerance. Bluegrass, bromegrass, orchardgrass, and timothy should be established for at least 6 months and fescue for 24 months at the time of application or injury may result. Application to fescue may result in stunting and seedhead suppression. Do not apply to ryegrass or pastures containing desirable alfalfa or clovers. Ally is persistent in soil, and crop rotation guidelines on the label must be followed.
Banvel, 4 lb a.e.	Annuals: 1 to 1½ pt Biennials: ½ to 3 pt Perennials: 1 to 12 pt	Use lower rates for susceptible annuals when they are small and actively growing and for susceptible biennials in the early rosette stage. Use higher rates for larger weeds, for less susceptible weeds, for established perennials in dense stands, and for certain woody brush species. Be cautious of spray drift.
Crossbow	Annuals: 1 to 2 qt Biennials and herbaceous perennials: 2 to 4 qt Woody perennials: 6 qt	Apply to foliage during warm weather when brush and broadleaf weeds are actively growing. When applying as a spot spray, thoroughly wet all foliage. See herbicide label for more specific rate recommendations. Be cautious of spray drift. Best control of multiflora rose occurs when application is during early to mid-flowering stage.
Roundup	1 to 2% solution (spot treatment)	Controls a variety of herbaceous and woody brush species, such as multiflora rose, brambles, poison ivy, and quackgrass. Spray foliage of target vegetation completely and uniformly, but not to point of runoff. Avoid contact with desirable nontarget vegetation. Consult label for recommended timing of application for maximum effectiveness on target species. No more than 1/10 of any acre should be treated at one time. Further applications may be made in the same area at 30-day intervals. Use only where livestock movement can be controlled to prevent grazing for 14 days. Treated areas can be reseeded after 14 days.
Spike 20P	10 to 20 lb	For control of brush and woody plants in rangeland and grass pastures. Requires sufficient rainfall to move herbicide into root zone. May kill or injure desirable legumes and grasses where contact is made. Injury is minimized by applying when grasses are dormant. Do not apply on or near field crops or other desirable vegetation. Do not apply where soil movement is likely. Refer to product label for additional restrictions.
Stinger, 3 lb a.e.	⅔ to 1⅓ pt	Apply when weeds are young and actively growing. Grasses are tolerant, but new grass seedlings may be injured. For Canada thistle, apply to thistle at least 4 in. tall but before thistle reaches bud stage. Do not spray pastures containing desirable forbs, such as alfalfa or clover, unless injury can be tolerated. Do not use hay or straw from treated areas for composting or mulching on susceptible broadleaf crops. Refer to product label for additional precautions.

may be used to control broadleaf weeds in seedling alfalfa. Be sure to apply Buctril while weeds are small, and use precautions to avoid an adverse effect on the crop. (See Table 16.08 for specific weed control ratings and Table 16.09 for rates and remarks.)

Established legumes

The best weed-control practice in established forage legumes is maintenance of a dense, healthy stand with proper management techniques. Chemical weed control in established forage legumes is often limited to late fall or early spring applications of herbicide. **Sencor** or **Lexone** (metribuzin), **Sinbar** (terbacil), and **Velpar** (hexazinone) are applied after the last cutting in the fall or in the early spring. These herbicides control many broadleaf weeds and some grasses, too. **Kerb** (pronamide) is used for grass control and is applied in the fall after the last cutting. The herbicide **2,4-DB** controls many broadleaf weeds in established alfalfa; it should be applied when the weeds are small and actively growing. Refer to Tables 16.08 and 16.09 for additional remarks and weed control suggestions.

Once grass weeds have emerged, they are particularly difficult to control in established alfalfa. **Poast Plus** may be used in established alfalfa for postemergence control of annual and some perennial grasses. Optimum grass control is achieved if Poast Plus is applied when grasses are small and before the weeds are mowed.

Table 16.08 outlines current suggestions for weed-control options in legume forages. The degree of control will often vary with weed size, application rate, and environmental conditions. Be sure to select the correct herbicide for the specific weeds to be controlled (Table 16.08). Refer to Table 16.10 for graz-

Table 16.07. Restrictions on Herbicides Used in Permanent Grass Pastures

Herbicide name		Days after treatment before use				
		Grazing		Grass hay		Slaughter withdrawal
Trade	Common	Beef	Dairy	Beef	Dairy	
Ally	metsulfuron	0	0	0	0	0
Banvel	dicamba	0	7 to 60[a]	0	37 to 90[a]	30
Crossbow	triclopyr + 2,4-D	0	14	7	365	3
Many	2,4-D	0	7 to 14[b]	30	30	3 to 7[b]
Stinger[c]	clopyralid	0	0	0	0	0
Roundup	glyphosate					
Spot-treat		14	14	14	14	. . .[d]
Renovation		56	56	56	56	. . .[d]
Spike 20P	tebuthiuron	(spot treatment)				
<20 lb/acre		0	0	365	365	. . .[d]
>20 lb/acre		Do not use for livestock for 1 year				
Weedmaster	dicamba + 2,4-D	0	7	37	37	30

[a] Varies with rate used per acre — see label.
[b] Labels vary (withdrawal unnecessary if more than 14 days after treatment).
[c] Do not transfer livestock onto a broadleaf crop area within 7 days of grazing treated area.
[d] No information available.

Table 16.08. Effectiveness of Herbicides on Weeds in Legume and Legume-Grass Forages

This table compares the relative effectiveness of herbicides on individual weeds. Ratings are based on labeled application rate and weed size or growth stage. Performance may vary due to weather and soil conditions or other variables.

Weed	Balan	Buctril	Butyrac	Eptam	Gramoxone Extra	Kerb	Poast Plus	Roundup[a,b]	Sencor/ Lexone[a]	Sinbar	Velpar
Winter annual											
Brome, downy	9	0	0	9	9	9	9	9	9	9	8
Chickweed, common	8	6	6	7	9	8	0	10	9	9	9
Henbit	5	8	6	9	9	8	0	8	9	9	8
Mustard, wild	0	8	10	6	9	5	0	9	9	9	9
Pennycress, field	0	9	8	6	9	5	0	10	9	9	9
Shepherdspurse	0	9	9	7	9	5	0	9	9	9	9
Yellow rocket	0	7	8	0	8	0	0	9	9	8	9
Summer annual											
Barnyardgrass	9	0	0	9	8	8	10	10	6	6	7
Crabgrass spp.	9	0	0	9	6	8	9	9	5	7	7
Foxtail spp.	9	0	0	9	9	8	10	10	6	7	7
Lambsquarters, common	9	10	8	9	9	6	0	9	9	9	9
Nightshade spp.[c]	0	9	8	8	9	6	0	9	5	6	6
Panicum, fall	9	0	0	9	9	6	10	10	6	6	6
Pigweed spp.	9	8	8	9	9	6	0	10	9	8	9
Ragweed, common	0	9	9	5	9	5	0	9	8	8	8
Smartweed, Pennsylvania	0	9	6	5	9	5	0	9	9	8	8
Perennial											
Canada thistle	0	0	0	0	0	0	0	9	0	0	0
Dandelion	0	0	7	0	0	0	0	8	8	6	7
Dock, curly	0	0	5	0	0	0	0	9	6	6	6
Nutsedge, yellow	0	0	0	8	0	0	0	7	0	0	0
Orchardgrass	5	0	0	6	5	7	6	8	5	5	6
Quackgrass	5	0	0	8	5	8	7	9	5	5	5

10 = 95 to 100%, 9 = 85 to 95%, 8 = 75 to 85%, 7 = 65 to 75%, 6 = 55 to 65%, 5 = 45 to 55%, 0 = less than 45% control or not labeled.
[a] Lexone, Sencor, and Roundup are labeled for use in mixed legume-grass forages. No other herbicides are cleared for this use.
[b] Spot treatment only.
[c] Control of different species may vary.

ing and harvesting restrictions for forage legumes. Always consult the herbicide label for specific information about the use of a given product.

Acreage conservation reserve program

Investing in good weed control on Acreage Conservation Reserve (ACR) land will help alleviate some problem weeds when rotating back to row crops. For example, perennial broadleaf weeds such as hemp dogbane and common milkweed may be controlled or suppressed in small-grain production or when a perennial grass or legume species is grown. In addition, mowing or alternative herbicide options may be available. Whether you use tillage, mowing, herbicides, or combinations, the best approach is to remain flexible and use cost-effective methods that fit your weed problems and management system.

Table 16.09. Weed Control in Legume Forages

Herbicide	Legume	Time of application	Broadcast rate/acre	Remarks (see Table 16.10 for haying restrictions)
Seedling year				
Balan 1.5EC	Alfalfa, birdsfoot trefoil, red clover, ladino clover, alsike clover	Preplant incorporated	3 to 4 qt	Apply shortly before seeding. Do not use with any companion crop of small grains.
Eptam 7E,10G	Alfalfa, birdsfoot trefoil, lespedeza, clovers	Preplant incorporated	3½ to 4½ pt (7E) 30 lb (10G)	Apply shortly before seeding. Do not use with any companion crop of small grains.
Gramoxone Extra	Alfalfa only	Between cuttings	12.8 fl oz	Apply within 5 days after cutting and before alfalfa regrowth is 2 in. Add surfactant according to label instructions. Do not apply more than twice during seedling year. *Gramoxone Extra is a restricted-use pesticide.*
Buctril 2E Buctril Gel	Alfalfa only Alfalfa only	Postemergence Postemergence	16 to 24 fl oz 8 to 12 fl oz	Apply in the fall or spring to seedling alfalfa with at least 4 trifoliate leaves. Apply to weeds at or before the 4-leaf stage or 2 in. in height (whichever is first). May be tank-mixed with 2,4-DB for improved control of pigweed; however, crop burn may occur from this mixture, especially under warm, humid conditions. Eptam, previously used, may enhance Buctril burn to alfalfa. Do not apply when temperatures are likely to exceed 70°F during or for 3 days following application or when the crop is stressed. Do not add a surfactant or crop oil.
Butyrac 200 or Butoxone 200	Alfalfa, birdsfoot trefoil, ladino clover, red clover, alsike clover, white clover	Postemergence	1 to 3 qt (amine)	Use when weeds are less than 3 in. tall or less than 3 in. across if rosettes. Use higher rates for seedling smartweed or curly dock. May be tank-mixed with Poast Plus. *Do not use on sweet clover.*
Kerb 50W	Alfalfa, birdsfoot trefoil, crown vetch, clovers	Postemergence	1 to 3 lb	In fall-seeded legumes, apply after legumes have reached trifoliate stage. In spring-seeded legumes, apply next fall. *Kerb 50W is a restricted-use pesticide.*
Poast Plus	Alfalfa only	Postemergence	1⅛ to 2¼ pt	Best grass control is achieved when applications are made prior to mowing. If tank-mixed with 2,4-DB, follow 2,4-DB harvest and grazing restrictions and add no additives with this tank-mix. Do not apply more than a total of 9.75 pt of Poast Plus per acre in 1 season.
Established stands				
Butyrac 200 or Butoxone 200	Alfalfa only	Growing	1 to 3 qt (amine)	Spray when weeds are less than 3 in. tall or less than 3 in. wide if rosettes. Fall treatment of fall-emerged weeds may be better than spring treatment. May be tank-mixed with Poast Plus.
Kerb 50W	Alfalfa, birdsfoot trefoil, crown vetch, clovers	Growing or dormant	1 to 3 lb	Apply in the fall after last cutting, when weather and soil temperatures are cool. *Kerb 50W is a restricted-use pesticide.*
Sencor or Lexone	Alfalfa and alfalfa–grass mixtures	Dormant	¾ to 2 pt (4L) ½ to 1⅓ lb (75 DF)	Apply once in the fall or spring before new growth starts. Rate is based upon soil type and organic-matter content. Higher rates may injure grass component. Do not use on sandy soils or soils with pH greater than 7.5.
Sencor	Alfalfa	Postdormant	1 to 1⅓ lb (75 DF)	May be applied postdormant but prior to 3 in. of alfalfa top growth when impregnated on dry fertilizer.
Sinbar 80W	Alfalfa only	Dormant	½ to 1½ lb	Apply once in the fall or spring before new growth starts. Use lower rates for coarser soils. Do not use on sandy soils with less than 1 percent organic matter. Do not plant any crop for 2 years after application.
Velpar L	Alfalfa only	Dormant	1 to 3 qt	Apply in the fall or spring before new growth exceeds 2 in. in height. Can also be applied to stubble after hay crop removal but before regrowth exceeds 2 in. Do not plant any crop except corn within 2 years of treatment. Corn may be planted 12 months after treatment provided deep tillage is used.
Poast Plus 1E	Alfalfa only	Postemergence	1⅛ to 2¼ pt	Best grass control is achieved when applications are made prior to mowing. If tank-mixed with 2,4-DB, follow 2,4-DB grazing and harvest restrictions. Do not apply more than a total of 9.75 pt of Poast Plus per acre in 1 season.

Table 16.09. Weed Control in Legume Forages (cont.)

Herbicide	Legume	Time of application	Broadcast rate/acre	Remarks: See Table 16.10 for haying restrictions.
Gramoxone Extra	Alfalfa only	Dormant	1½ to 2 pt	For dormant season, apply after last fall cutting or before spring growth is 1 in. tall. Weeds should be succulent and growing at the time of application. Do not apply if fall regrowth is more than 6 in. *Gramoxone Extra is a restricted-use pesticide.*
		Between cuttings	12.8 fl oz	Between cutting treatments should be applied immediately after hay removal within 5 days after cutting and with less than 2 in of growth. Weeds germinating after treatment will not be controlled. *Gramoxone Extra is a restricted-use pesticide.*
Roundup	Alfalfa, clover, and alfalfa or clover–grass mixtures	Growing	1 to 2% solution (spot treatment)	No more than ⅒ of any acre should be treated at one time. Further applications may be made in the same area at 30-day intervals. Avoid contact with desirable, nontarget vegetation because damage may occur. Refer to label for recommended timing of application for maximum effectiveness on target species.
Treflan TR-10 4EC	Alfalfa	Dormant or after a cutting during the growing season	20 lb 4 pt	A single rainfall or overhead sprinkler irrigation of 0.5 in. or more, flood irrigation, or furrow irrigation after application is required to activate the herbicide. If activation does not occur within 3 days after application, incorporate using equipment that will provide thorough soil mixing with minimum damage to the established alfalfa. Treflan 4EC may be surface-applied or applied by chemigation. Do not apply Treflan TR-10 by chemigation.

Table 16.10. Herbicides Used in Forage Legumes and Restrictions

Herbicide name		Applied on/at		Days before	
Trade	Common	Forage[a]	When[a]	Graze	Hay
Seedling legumes					
Balan	benefin	AL, CL, BT	PPI	0	0
Eptam	EPTC	AL, CL, BT	PPI	...[b]	...[b]
Butyrac, Butoxone	2,4-DB	AL, CL, BT	Post	60	60
Buctril	bromoxynil	AL	Postfall	60	60
		AL	Postspring	30	30
Gramoxone Extra	paraquat	AL	After cut[c]	30	30
Poast Plus	sethoxydim	AL	Post	7	20
Established legumes					
Many	2,4-DB	AL	Post	30	30
Gramoxone Extra	paraquat	AL	After cut[c]	30	30
Poast Plus	sethoxydim	AL	Post	7	20
Roundup	glyphosate	AL, CL, BT	Spot-treat	14	14
Roundup	glyphosate	AL, CL, BT	Renovate	56	56
Gramoxone Extra	paraquat	AL	Dormant	60	60
Kerb	pronamide	AL, CL, BT	Dormant	120	120
Lexone	metribuzin	AL	Dormant	28	28
Sencor	metribuzin	AL	Dormant	28	28
Sencor	metribuzin	AL	Postdormant[d]	60	60
Sinbar	terbacil	AL	Dormant	...[b]	0
Treflan	trifluralin	AL	Dormant or after cutting	21	21
Velpar	hexazinone	AL	Dormant	30	30

[a] AL = alfalfa, CL = clover (red, alsike, or ladino), BT = birdsfoot trefoil, PPI = preplant-incorporated.
[b] No grazing information on label.
[c] Between cuttings (less than 5 days after cut with less than 2 in. regrowth).
[d] If impregnated on dry fertilizer.

Clover, alfalfa, or other forage legumes may be one of the best options for ACR acres. These cover crops help conserve soil, improve soil structure, and add nitrogen to the soil. Clover and alfalfa can be quite economical, particularly if grown for at least two consecutive years. The use of a herbicide for legume establishment can allow a vigorous legume stand and alleviate the need for weed control measures later. If annual broadleaf weeds become a problem, consider applying **2,4-DB** or mowing. Herbicides for use on

forage legumes on ACR acres include some of those registered for commercial production fields (Table 16.08). In addition, **Treflan** (trifluralin) or **Prowl** (pendimethalin) may be used preplant incorporated to control annual grasses and some small-seeded broadleaf weeds. Some stand reduction may occur with Treflan or Prowl, but good weed control can compensate to allow for good establishment of the legume. **Fusilade DX** (fluazifop) or **Poast Plus** (sethoxydim) may be used for postemergence grass control on some forage legumes on ACR land. With many of these products, haying and grazing are not allowed; be sure to follow all restrictions imposed by the pesticide label.

Oats are commonly grown as a cover crop on set-aside acres. Oat seed is inexpensive and easy to obtain. If the Agricultural Stabilization and Conservation Service (ASCS) does not require clipping before seed maturity, oats can be reseeded for late summer and fall cover. Wheat, rye, or barley are other small-grain cover crop possibilities.

Sowing weed-free, small-grain seed is the first step toward minimizing weed problems. Small grains generally provide relatively good cover until they mature or the area is mowed; then weeds can soon proliferate. However, winter wheat or rye may be sown in the spring, and without the overwintering period (vernalization), little or no seed production occurs and a dense cover remains. Annual broadleaf weeds can be controlled by mowing and by the use of the herbicides listed in Table 16.03. Tillage before small-grain planting will help control established weeds.

Sorghum-sudan grass can make a rapid, vigorous cover that also effectively suppresses many weeds. Although herbicides are rarely needed in sorghum-sudan grass stands, mowing and tillage may be difficult, and viable seed sometimes causes weed problems the next year.

Planting a small-grain/legume combination is another option for set-aside. Using the small grain as a companion crop may help reduce weed pressure and alleviate the need for herbicides. If weeds become a problem, refer to Table 16.08 for more information in selecting the appropriate herbicide.

In addition to those herbicides listed in Table 16.08, **Buctril** may be used to control broadleaf weeds in seedling alfalfa-grass mixes on Conservation Reserve Program (CRP) acres. Refer to current label rates and restrictions.

Acreage Conservation Reserve land may offer an opportunity for controlling certain problem weeds, such as perennials, and may keep other, more common weeds in check. By managing ACR land this year, controlling weeds in future row crops will be less difficult and more economical.

Chapter 17.

Management of Field Crop Insect Pests

Integrated pest management

Integrated pest management (IPM) has had a close association with the production of field crops, beginning long before its formal introduction in Illinois by the Cooperative Extension Service during the early 1970s. Farmers have practiced pest management for hundreds of years on this continent and for a much longer period in the Old World. Integrated pest management strategies such as multiple crop rotations, early harvesting, strip cropping, mechanical cultivation, trap cropping, and manipulating planting dates have been relied upon by farmers for centuries.

Because of the lack of diversity of organisms within a crop field and the frequent human-imposed disturbances placed upon fields — such as tillage operations, mowing, or the use of pesticides — certain populations of organisms may increase in numbers and threaten the profitable production of a given crop. Populations of organisms whose densities reach levels that begin to compete with the production of human-desired quantities of food and fiber are referred to as pests. As used in this chapter, the term "pest" refers to any insect that is injurious to cultivated crops. Although "pest" is often used interchangeably with "insect," pests of field crops include insects, weeds, nematodes, plant diseases, and rodents. Control measures for all pests should be integrated into a crop management system that ensures economically viable crop production and environmental stewardship.

Although the use of pesticides has become a standard practice for reducing pest populations, certain problems arise from sole reliance on pesticides. Because of concerns about insecticide resistance, secondary pest resurgence, and threats to the environment and public health in the 1960s and 1970s, the philosophy of integrated pest management (IPM) became popular. In the 1990s, concerns about contamination of surface water and groundwater, residues of pesticides in food, and other pesticide-related issues continue to focus attention on the need for judicious use of pesticides. More than ever, IPM methodologies are vital for both a sustainable national agriculture and environmental protection, as shown by the Clinton administration's proposal calling for the use of IPM on 75 percent of the nation's managed acres by the year 2000.

Economic (action) thresholds

One of the most familiar features of field-crop IPM programs is scouting fields for insect pests and basing treatment decisions on economic thresholds, popularly referred to as "action thresholds." The economic threshold (ET) is that pest density at which some control should be exerted to prevent a pest population from increasing further and causing an economic loss. Examples of economic thresholds for some insect pests in various crops include:

- black cutworms in corn: Apply a postemergence rescue treatment when 3 percent or more of the plants are cut and larvae are still present.
- bean leaf beetles in soybeans: When defoliation reaches 30 percent (before bloom) and there are 5 or more beetles per foot of row.
- potato leafhoppers in alfalfa: Treatments are recommended when a certain number of potato leafhoppers are collected per sweep at a given plant height (for example, 0.2 leafhopper per sweep when plants are 0 to 3 inches tall).

Environmental and economic conditions are unstable, so several factors may alter an economic threshold: value of the crop (as the price paid for the crop increases, the economic threshold decreases); cost of control (as the cost of control increases, the economic threshold also increases); and crop stress (as the amount of stress on a crop increases, the economic threshold may decrease). For example, an insecticide may be economically justified for an insect pest population that is below the

economic threshold if the crop is under stress from a lack of moisture, severe weed pressure, a plant disease, or a lack of proper fertility. Economic thresholds should be adjusted to reflect changes in market prices, cost of control, and crop stress.

Improved pest-monitoring techniques and a growing acceptance of the ET concept have encouraged reductions in pesticide use. However, current thresholds do not incorporate environmental costs. Although ETs generally have reduced excessive use of insecticides, ETs do not reflect any of the potential environmental hazards associated with a pesticide treatment. Environmental hazards associated with pesticide use include reduced densities of beneficial insects like predators and parasitoids; pesticide residues on food products; pesticide detections in surface and groundwater supplies; and wildlife kills. Before environmental thresholds can be used on a large-scale basis, monetary values must be attached to the potential hazards posed by pesticide use.

Scouting field crops for insects

One of the keys to a successful IPM program is regular monitoring of field-crop conditions and insect infestations. A scouting trip through a field reveals which insect pests are present, what stage of growth insect pests and the crop are in, whether the insects are parasitized or diseased, whether an infestation is increasing or decreasing, and the condition of the crop. This information can be used to determine whether a control measure may be needed. A scouting program also requires accurately written records of the field location, current field conditions, a history of previous insect pest infestations and insecticide use, and a map locating current infestations. These records will enable a grower to keep track of each field and anticipate or diagnose unusual crop conditions.

Insect pests can be monitored in several ways. Usually the insects are counted, or the amount of crop injury is estimated. Counts of insects are commonly expressed as number per plant, number per foot of row, number per sweep, or number per unit area (square foot or acre). Estimated crop injury is usually expressed as a percentage. Methods of scouting for insects include collecting insects with a sweep net, shaking the crop foliage and counting dislodged insects, counting insects on plants, and using traps.

It is important to conduct representative surveys of a field. A field is a unit of land that has been treated the same way agronomically (same planting date, same variety, same crop rotation, same fertility level, etc.). For example, if a 40-acre field has been planted to two corn varieties, 20 acres devoted to each variety, the two 20-acre units should be scouted as different fields. Fields should be scouted at least once a week; inspections should be made in several representative areas of each field. Avoid scouting the edges of a field unless specifically looking for an insect that first invades field edges (grasshoppers, spider mites, stalk borers).

A producer should answer the following questions when thinking about implementing a scouting program or hiring a crop consultant:

1. Do you have the time to scout?
2. Do you know how and when to scout?
3. Can you identify insect pests?
4. Can you identify beneficial insects?
5. Can you accurately sample insect populations, at least well enough to feel comfortable with your decisions?
6. Can you accurately measure crop damage?
7. Do you know and understand economic thresholds?
8. Are you aware of all of the insect control alternatives?
9. Can you prepare a thorough set of crop scouting records?

If a producer answers *no* to most of these questions but wants to begin an active IPM program, the services of a professional crop consultant should be considered.

Types of insect pests

Insects that inhabit cultivated crops and rarely if ever reach densities sufficient to cause economic losses are referred to as "nonpests." Common examples of these insects in Illinois field crops include pea aphid on alfalfa, yellow woollybear on corn, and painted lady on soybeans. Other field-crop insects reach damaging densities only as the result of unusual environmental conditions or frequent nonselective use of an insecticide. These insects are referred to as "occasional pests." Most of the insect pests in Illinois field crops are occasional pests — for example, green cloverworm and twospotted spider mite (not an insect) on soybeans, corn leaf aphid and black cutworm on corn, and grasshoppers and meadow spittlebug on alfalfa.

Some insects, referred to as "perennial pests," inflict economic losses on a frequent basis. To limit the economic losses they cause, periodic control measures must be used when their densities increase. Examples of perennial insect pests in Illinois field crops are not common; however, some entomologists consider corn rootworms to be perennial pests in continuous corn. Some insects are referred to as "severe pests." A familiar example of this type of pest that continually plagues sweet-corn producers is the corn earworm.

IPM: more than just scouting

Integrated pest management is far more complex than just scouting fields for insect pests, having knowledge of economic thresholds, and using pesticides judiciously. A well-designed IPM program should integrate several management strategies for insects, plant diseases, and weeds while maintaining agricultural profitability and environmental quality. Effective pest managers should anticipate potential pest problems and attempt to modify existing crop production practices if they continually lead to pest outbreaks, yield losses, and overuse of pesticides.

This objective of using pesticides judiciously is most often accomplished by blending pest control tactics. Pest management programs may include cultural, mechanical, physical, biological, genetic, regulatory, and chemical control methods. Some common tactics used in field crop pest management programs are (1) planting pest-resistant crop varieties; (2) rotation of crops; (3) changing tillage practices; (4) variation of planting and harvest times; (5) biological control; (6) planting trap crops; (7) proper fertilization of soil; (8) proper sanitation; and (9) effective water management programs.

Host plant resistance. Most farmers in Illinois choose crop varieties primarily according to their yield potential and the time required to reach maturity. Although resistance to pathogens may determine the selection of a particular variety, only rarely is resistance to insects considered. However, certain varieties of field crops offer some level of resistance or tolerance to specific insect pests. For example, different corn hybrids have different degrees of tolerance or resistance to leaf feeding by first-generation European corn borers and sheath-collar feeding by second-generation borers. Resistant or tolerant varieties can also be found for the following insects: corn rootworms in corn; bean leaf beetle, Mexican bean beetle, potato leafhopper, and twospotted spider mite in soybeans; Hessian fly in wheat; and alfalfa weevil, aphids, and potato leafhopper in alfalfa.

As a first step in managing insect pests in field crops, consider resistance or tolerance when selecting a crop variety. At the very least, solicit from the seed dealer information about the variety selected and its ability to resist or tolerate insect infestations.

Crop rotation. Crop rotation greatly influences whether a soil insect problem may occur. The complex of insect pests changes according to the types of crops rotated, the sequence of the crop rotation, and the amount of time devoted to the production of a particular crop before planting a new crop. The brief summaries that follow should help producers determine the likelihood of an insect outbreak in different crop rotation schemes.

Corn after soybeans. The potential for soil insect problems in corn after soybeans is generally low, and the use of a soil insecticide is not recommended. This recommendation remains true even in those areas of the state where corn rootworm larvae have injured roots in fields of corn after soybeans. A lindane or diazinon + lindane planter-box seed treatment will be adequate to protect the seeds from seedcorn beetles, seedcorn maggots, and wireworms.

Corn after corn. The potential for rootworm damage exists wherever corn is planted after corn in Illinois. A rootworm soil insecticide is applied to approximately 88 percent of continuous corn acreage, even though economic infestations generally occur in only half of all continuous cornfields.

Corn after legumes. Cutworms, grape colaspis, white grubs, and wireworms occasionally damage corn planted after clover or alfalfa, and adult northern corn rootworms are sometimes attracted to legumes or to weed blossoms in legumes for egg laying, especially in years when beetles are forced to leave adjacent fields of drought-stressed corn to seek food. The use of a seed treatment is recommended, but producers may consider the use of a soil insecticide for this cropping sequence.

Corn after small grain. There is a slight potential for injury caused by wireworms, seedcorn beetles, and seedcorn maggots in corn after small grain, particularly wheat. In most instances, a diazinon + lindane planter-box seed treatment is adequate. However, excessive weed cover in small-grain stubble may have been attractive to northern corn rootworm beetles for egg laying if the adults moved from adjacent fields of drought-stressed corn.

Corn after grass sod. Corn billbugs, sod webworms, white grubs, and wireworms may cause stand reductions when corn is planted after bluegrass, brome, fescue, rye, or wheat. If a producer decides to plant corn into an established field of grass sod, an insecticide, applied either before or at planting, should be considered for the control of wireworms and white grubs. Rescue treatments applied after the damage is noticed are not effective. If a stand is being severely thinned by wireworms or white grubs, the only options are to accept the reduced stand or replant and apply an insecticide during the replanting operation.

Corn after sorghum. A planter-box seed treatment of diazinon or diazinon + lindane will protect the seeds from seedcorn maggots.

Tillage. The type of equipment and the timing (fall or spring), depth, and frequency of tillage operations can influence the survival of some insect species. Tillage operations may alter soil temperature, soil moisture, aeration, organic matter content, and bulk density of the soil, each of which may have a direct effect on some insects' survival and development. Often of greater importance to an insect population are the indirect effects occasionally associated with certain tillage systems. For example, poor weed control in some tillage systems enhances the likelihood of an increase in specific insect populations (black cutworms, stalk borers). However, sweeping predictions about how all insects respond to a certain tillage practice are not appropriate.

Insects that may cause problems in mulch-till, ridge-till, or no-till corn can be divided into two categories: soil insects and foliage-feeding insects. The soil insect complex includes billbugs, corn rootworm larvae, cutworms, seedcorn beetles, seedcorn maggots, white grubs, and wireworms. Foliage-feeding insects include armyworms, brown and onespotted stink bugs, European corn borers, and stalk borers.

The insects most affected by changes in tillage practices are those that overwinter in the soil and become active during the early stages of crop growth. Soil- and litter-dwelling insects are affected more than the foliage-feeding insects. In most instances, a greater diversity of insects is present in reduced-tillage sys-

tems, but this greater diversity does not always result in predictable increases or decreases in crop injury because both pests and their natural enemies respond to tillage practices.

Much less is known about the influence of various cultural practices on insects in soybeans. Most soybean insect pests are defoliators or pod feeders. They are often very mobile; some immigrate from other regions of the country, and most move readily from field to field. The effect of a single soybean producer's tillage practices on the potential for injury caused by defoliators is insignificant. Slugs, which are not insects, occasionally cause significant injury to no-till soybeans. Densities of slugs are often highest in no-till systems where crop residue is greatest; their densities are lowest where no residue is present. Because of the residue cover and inclusion of soybeans in no-till rotational systems, slug problems are expected to increase as conservation tillage becomes more common.

Variation in planting and harvest times. To combat Hessian flies, wheat producers are encouraged to follow some proven pest management strategies that involve tillage, planting resistant varieties, and altering planting dates. Because chemical controls are neither a practical nor reliable solution to Hessian fly problems, the following tactics are recommended to manage this insect pest:

- Destroy wheat stubble and volunteer wheat.
- Plant resistant or moderately resistant wheat varieties.
- Plant wheat after the fly-free date (Table 17.01).

Many producers continue to plant winter wheat before established "fly-free dates." By not adhering to these dates, growers are placing greater pressure upon the ability of resistant wheat varieties to withstand Hessian fly infestations. Consequently, the potential longevity and usefulness of Hessian fly–resistant wheat varieties will be shortened. The dates listed in Table 17.01, ranging from September 17 at the Wisconsin border to October 12 at the southern tip of Illinois, represent the earliest dates that wheat should be seeded to avoid egg laying by the summer to early fall generation of Hessian fly females. Where wheat is seeded on or after the fly-free date for a specific location, Hessian fly adults emerge and die before the crop is out of the ground.

Planting dates also influence the potential severity of infestations of other insects. For instance, corn that is planted early (the fields with the tallest corn) should be monitored closely during June and early July for signs of whorl feeding by European corn borer larvae. The fields with the tallest corn are the most attractive to moths that are laying eggs for the first generation. Late-planted cornfields are most susceptible to economic infestations of the second generation of corn borers. On the other hand, early planted corn usually escapes infestations by black cutworms, and late-planted corn is more likely to be attacked.

Although planting date has little effect on insects in alfalfa, alfalfa weevils and potato leafhoppers can be managed in part by the timing of harvest. An early first cutting often reduces larval alfalfa weevil densities by exposing the larvae to sunlight, drier conditions, and increased predation. Harvesting affects leafhopper densities in second and third cuttings by removing leafhopper eggs from the field along with the hay crop and by killing many immature leafhoppers.

Biological and natural control. Through a process called "natural control," certain insects and diseases suppress populations of pest insects without our help. For example, European corn borer populations are often reduced by *Beauveria bassiana*, a fungus, or by *Nosema pyrausta*, a protozoan. These diseases are part of the natural ecosystem and exert their influence without human intervention. However, the process of natural control may alter pest management decisions. An abundance of predators or parasitoids or a significant percentage of diseased pests may suggest that an insecticide application is not necessary.

Through a process more appropriately called "applied biological control," predators, parasitoids, or disease pathogens are introduced artificially into a field. Although considerable research has been conducted, the introduction of beneficial insects and disease pathogens into corn and soybean fields to control pest insects has not been very effective. Field crop environments change constantly, so beneficial organisms have a difficult time becoming established.

The use of microbial insecticides offers considerably more potential within an IPM program. Microbial insecticides are made of microscopic living organisms (viruses, bacteria, fungi, protozoa, or nematodes) or the toxins produced by them. These insecticides can be formulated to be applied as sprays, dusts, or granules. Their chief advantage is an extremely low toxicity to nontarget animals and humans. The most familiar microbial insecticides (DiPel and similar products) are those that contain toxins produced by *Bacillus thuringiensis*, a bacterium.

Insecticide selection: making choices. Insecticides should be used only after all other effective insect control alternatives have been explored. The decision to use an insecticide should be based upon (1) information obtained from scouting; (2) knowledge of economic thresholds; and (3) an awareness of the potential benefits and risks associated with a treatment. If used improperly, insecticides can cause detrimental effects to the applicator, the crop, or the environment. Insecticides can provide effective control, but they should be used judiciously and in combination with nonchemical methods that can be incorporated into the cropping system. After a decision to use an insecticide has been made, several questions should be considered carefully:

1. Is the pest you want to control listed on the pesticide label?
2. Does the label state that the insecticide will control the pest, or does the word "suppression" appear on the label?

Table 17.01. Average Date of Seeding Wheat for the Highest Yield

County	Average date of seeding wheat for the highest yield	County	Average date of seeding wheat for the highest yield
Adams	Sep. 30-Oct. 1	Lee	Sep. 19-21
Alexander	Oct. 12	Livingston	Sep. 23-25
Bond	Oct. 7-9	Logan	Sep. 28-Oct. 3
Boone	Sep. 17-19	Macon	Oct. 1-3
Brown	Sep. 30-Oct. 2	Macoupin	Oct. 4-7
Bureau	Sep. 21-24	Madison	Oct. 7-9
Calhoun	Oct. 4-8	Marion	Oct. 8-10
Carroll	Sep. 19-21	Marshall-Putnam	Sep. 23-26
Cass	Sep. 30-Oct. 2	Mason	Sep. 29-Oct. 1
Champaign	Sep. 29-Oct. 2	Massac	Oct. 11-12
Christian	Oct. 2-4	McDonough	Sep. 29-Oct. 1
Clark	Oct. 4-6	McHenry	Sep. 17-20
Clay	Oct. 7-10	McLean	Sep. 27-Oct. 1
Clinton	Oct. 8-10	Menard	Sep. 30-Oct. 2
Coles	Oct. 3-5	Mercer	Sep. 22-25
Cook	Sep. 19-22	Monroe	Oct. 9-11
Crawford	Oct. 6-8	Montgomery	Oct. 4-7
Cumberland	Oct. 4-5	Morgan	Oct. 2-4
DeKalb	Sep. 19-21	Moultrie	Oct. 2-4
DeWitt	Sep. 29-Oct. 1	Ogle	Sep. 19-21
Douglas	Oct. 2-3	Peoria	Sep. 23-28
DuPage	Sep. 19-21	Perry	Oct. 10-11
Edgar	Oct. 2-4	Piatt	Sep. 29-Oct. 2
Edwards	Oct. 9-10	Pike	Oct. 2-4
Effingham	Oct. 5-8	Pope	Oct. 11-12
Fayette	Oct. 4-8	Pulaski	Oct. 11-12
Ford	Sep. 23-29	Randolph	Oct. 9-11
Franklin	Oct. 10-12	Richland	Oct. 8-10
Fulton	Sep. 27-30	Rock Island	Sep. 20-22
Gallatin	Oct. 11-12	St. Clair	Oct. 9-11
Greene	Oct. 4-7	Saline	Oct. 11-12
Grundy	Sep. 22-24	Sangamon	Oct. 1-5
Hamilton	Oct. 10-11	Schuyler	Sep. 29-Oct. 1
Hancock	Sep. 27-30	Scott	Oct. 2-4
Hardin	Oct. 11-12	Shelby	Oct. 3-5
Henderson	Sep. 23-28	Stark	Sep. 23-25
Henry	Sep. 21-24	Stephenson	Sep. 17-20
Iroquois	Sep. 24-29	Tazewell	Sep. 27-Oct. 1
Jackson	Oct. 11-12	Union	Oct. 11-12
Jasper	Oct. 6-8	Vermilion	Sep. 28-Oct. 2
Jefferson	Oct. 9-11	Wabash	Oct. 9-11
Jersey	Oct. 6-8	Warren	Sep. 23-27
JoDaviess	Sep. 17-20	Washington	Oct. 9-11
Johnson	Oct. 10-12	Wayne	Oct. 9-11
Kane	Sep. 19-21	White	Oct. 9-11
Kankakee	Sep. 22-25	Whiteside	Sep. 20-22
Kendall	Sep. 20-22	Will	Sep. 21-24
Knox	Sep. 23-27	Williamson	Oct. 11-12
Lake	Sep. 17-20	Winnebago	Sep. 17-20
LaSalle	Sep. 19-24	Woodford	Sep. 26-28
Lawrence	Oct. 8-10		

3. Are you familiar with relevant university research and recommendations?
4. Is the recommended rate of application economical for your operation?
5. How toxic is the pesticide? Dermally? Orally?
6. Is the pesticide a restricted-use product?
7. Does this pesticide have the potential to contaminate groundwater, even when label recommendations are followed?
8. Will the use of this pesticide expose humans to health or safety risks?
9. Will the use of this pesticide threaten wildlife populations?

If these questions can be answered appropriately, insecticides can be used effectively within an integrated pest management program.

Key field crop insect pests

This section contains discussions of some of the key insect pests in field crops in Illinois, including descriptions, life cycles, current economic thresholds, and current management suggestions. However, a complete list of insecticides that can be used to control all of the potential insect pests has not been included. Tables that provide specific information about insecticides and their use for all of the insect pests that attack corn, soybeans, alfalfa, grain sorghum, small grains, and pasture are published in Chapter 1, "Insect Pest Management for Field and Forage Crops," in the current year's edition of the ***Illinois Agricultural Pest Management Handbook*** (formerly titled the *Illinois Agricultural Pest Control Handbook*). More complete

discussions of nonchemical methods of insect control in field crops are published in Chapter 2, "Alternatives in Insect Management: Field and Forage Crops," in the same pest management handbook. Color photographs and more information about scouting is published in the ***Field Crop Scouting Manual.***

Insect pests of alfalfa

Because of its lush growth, alfalfa is an excellent habitat for a variety of insects: species destructive to alfalfa and other crops; species that inhabit the alfalfa but have little or no effect on the crop; pollinating insects; incidental visitors; and predators and parasitoids of other insects. Because of its perennial growth, many species overwinter in alfalfa.

More than a hundred species of insects and mites are capable of reducing alfalfa yield, impairing forage quality, or reducing the vitality and longevity of the crop. However, only two insect species are considered key pests: the alfalfa weevil and the potato leafhopper.

Alfalfa weevil. The mature alfalfa weevil larva is about 3/8-inch long and has a black head. The curved body of the larva is green, with a white stripe along the center of the back. The adult alfalfa weevil is about 1/4-inch long and has a distinct snout. It is light brown, with a darker brown stripe along the center of the back.

In southern Illinois, when temperatures permit, adult weevils lay eggs throughout the fall and winter and into the spring. Because eggs begin to hatch about the time alfalfa is beginning its spring growth, larval injury occurs early in the spring. In northern Illinois, most eggs are laid in the spring. By the time larvae emerge, alfalfa is 6 to 10 inches tall and can tolerate more weevil feeding than the southern crop.

Newly hatched larvae feed in the growing tips. An early sign of injury is pinholes in newly opened leaves. As larvae grow larger, they shred and skeletonize the leaves. Heavily infested fields appear frosted because of the loss of green leaf tissue. Anything that slows spring alfalfa growth increases the impact of weevil injury.

When weevil larvae finish feeding, they spin netlike cocoons on the plants or in soil debris and pupate. After several days, the adults emerge and feed on alfalfa for a few weeks. Although adults cause only minor damage to alfalfa, signs of their feeding are obvious. They cause leaves to appear "feathered," and they scar the stems of the alfalfa plants. Both surviving larvae and newly emerged adults may severely damage regrowth after the first cutting. They remove early shoot growth, depleting food reserves in the roots and reducing the stand.

The adults eventually leave alfalfa fields to enter summer dormancy in sheltered sites. In the fall, most adults return to alfalfa, where they feed for a while before "hibernating." In southern counties, the adults mate and lay eggs, and both adults and eggs overwinter. Alfalfa weevils complete one generation each year.

The key to effective management of alfalfa weevils is timely monitoring. Growers in southern and central Illinois should inspect their fields closely in April, May, and June. Growers in northern counties should look carefully for larval injury during May and June. All growers should examine the stubble after the first cutting of alfalfa has been removed. Treatment for control of alfalfa weevils on the first crop of alfalfa may be warranted when there are 2 to 3 larvae per stem and 25 to 50 percent of the tips have been skeletonized, depending on the height of the crop and the vigor of growth. Tall, rapidly growing alfalfa can tolerate considerable defoliation without a subsequent loss in yield. After harvest, control may be warranted when larvae and adults are feeding on more than 50 percent of the crowns and regrowth is prevented for three to six days.

Parasitic wasps and a fungal disease may regulate alfalfa weevil populations in the spring. When scouting for alfalfa weevils, look for signs of parasitism and for diseased weevils (discolored, moving slowly, or moving not at all). When natural enemies suppress weevil numbers, insecticide treatments may not be necessary.

Potato leafhopper. The adult potato leafhopper is a green, wedge-shaped insect about 1/8-inch long. Nymphs resemble the adults but are smaller and wingless. Both have piercing, sucking mouthparts and are very active. The adults hop or fly, and the nymphs move rapidly, either sideways or backward, when disturbed.

Potato leafhoppers do not overwinter in Illinois. Prevailing spring winds carry adults northward from the Gulf Coast states, and leafhoppers first appear in alfalfa fields in Illinois near the end of May. The adults mate and begin laying eggs in stems and leaf veins. Nymphs emerge in about a week and begin feeding. Several generations may occur before cold temperatures kill the leafhoppers.

Both nymphs and adults suck fluids from alfalfa plants. Nymphs cause more damage than the adults. Initial injury is characterized by a V-shaped yellow area at the tips of the leaflets, often called "hopperburn" or "tipburn." As the injury progresses, the leaves turn completely yellow and may turn purple or brown and die. When infestations are heavy, injured plants are stunted and bushy. Leafhopper injury also causes plants to produce more sugars and less protein and vitamin A, resulting in lower-quality alfalfa. If leafhoppers deplete root reserves of the late-season growth of alfalfa, the plants will be less hardy and may not survive the winter.

Injury by potato leafhoppers is often confused with boron deficiency, plant diseases, or herbicide injury. The presence of the insect is often the key to diagnosing the problem. Sampling with a 15-inch diameter sweep net is the best method for monitoring populations of potato leafhoppers in alfalfa. Economic thresholds are

based on the number of leafhoppers per sweep of the sweep net.

When alfalfa is regrowing after a cutting, scouting for leafhoppers is critical. Tender, regrowing alfalfa is very susceptible to leafhopper injury. Taller, more mature alfalfa can tolerate more leafhopper injury, and the economic thresholds vary accordingly. An insecticide may be warranted for alfalfa up to 3 inches tall when there is an average of 0.2 leafhopper per sweep. The economic thresholds for 3- to 6-inch alfalfa, 6- to 12-inch alfalfa, and alfalfa taller than 12 inches are 0.5, 1, and 2 leafhoppers per sweep, respectively.

Sampling is very important. By the time symptoms of potato leafhopper injury appear, considerable yield and nutritional quality may have been lost. Monitoring should begin after first harvest and continue on a regular basis throughout the summer.

Insect pests of corn

Insects that attack corn generally are separated into two categories: those that attack the plant below ground and those that attack the plant above ground. Populations of below-ground insects are difficult to predict; responsive "rescue" treatments are ineffective for most. Consequently, many corn producers prevent infestations with crop rotation or application of soil insecticides. A list of soil insecticides that are suggested for control of corn rootworms, cutworms, wireworms, and white grubs is presented in Table 17.02.

Most below-ground insect pests in Illinois feed on underground parts of the corn plants. Corn rootworm larvae feed on and prune the roots; white grubs and grape colaspis feed on the root hairs and the roots; wireworms, seedcorn beetles, and seedcorn maggots attack the planted seeds; wireworms also will tunnel into the underground portion of the stem. Young cutworms feed on the leaves of seedling corn plants; older cutworms cut off the plants at, just below, or just above the soil surface. Webworms cause injury similar to that caused by cutworms. Hop vine borers drill into the underground portion of the stem and tunnel upward. Billbugs and stink bugs feed at the bases of the cornstalks; billbug larvae feed inside the lower portion of the stalk.

Above-ground insect pests include stalk-boring insects like the European corn borer and stalk borer; insects that feed primarily on the leaves, like armyworms, fall armyworms, flea beetles, and grasshoppers. Chinch bugs, corn leaf aphids, spider mites, and thrips suck the fluids from the plants at different times of the growing season. Corn rootworm beetles, Japanese beetles, and woollybear caterpillars will clip corn silks, interfering with pollination. Larvae of corn earworms, European corn borers, and fall armyworms feed on the ear.

Table 17.02. Insecticides Suggested for Control of Some Soil Insects in Illinois

Insecticide	Rootworms	Cutworms	Wireworms	White grubs
*Ambush 2E	—[a]	x[b]	—	—
*Asana XL	—	x	—	—
*Counter 15G	x	—	x	x
*Counter CR	x	—	x	x
Dyfonate II 15G	x	x	—	—
*Dyfonate II 20G	x	x	—	—
*Force 1.5G	x	x	x	x
*Force 3G	x	x	x	x
*Furadan 4F	x	—	x	—
*Holdem 20G	x	—	x	—
Lorsban 15G	x	x	—	—
Lorsban 4E	—	x	x	x
*Pounce 1.5G	—	x	—	—
*Pounce 3.2EC	—	x	—	—
*Thimet 15G	x	—	x	x
*Thimet 20G	x	—	x	x

* Use restricted to certified applicators only.
[a]— = The most economical rate and application of this insecticide is not labeled for control of this insect, or labeled only for suppression or aid in control of the insect.
[b]x = The most economical rate and application of this insecticide is labeled for control of this insect. Refer to label for rate, timing, and placement of application.

Black cutworm. Black cutworms occur sporadically as pests of corn in Illinois. When an outbreak develops, however, the resulting damage may be extensive. Black cutworms feed on seedling corn, which is very susceptible to any type of injury.

Black cutworm larvae vary in color from light gray to black, and are about 1½ inches long when fully grown. Numerous convex skin granules of different sizes give the cutworm a somewhat "greasy" and rough appearance. The moths (adults) have a robust body and a wingspan of about 1½ inches. They are dark gray, with a black, dagger-shaped marking toward the outer edge of the forewing.

Black cutworms probably do not overwinter in large numbers in Illinois. Evidence suggests that the moths fly into the Midwest from southern states early in the spring. Extension entomologists at the University of Illinois use sticky traps baited with synthetic female sex pheromone to monitor moth flight in the spring. A network of traps operated by cooperators throughout the state enables the entomologists to predict biological events in the black cutworm's life cycle.

Female moths lay eggs primarily on weedy vegetation, preferably on winter annuals. After the eggs hatch, the small larvae feed on these host plants. When herbicides or tillage destroys the weeds, the larvae begin feeding on corn seedlings.

The larvae pass through six or seven instars (stages of larval development). Their rate of development depends upon temperature: the larvae develop more quickly when the weather is warm. The first three instars are very small, and the larvae feed on the corn leaves. This injury, which is not economic, appears as small holes or bites in the leaves. The fourth through seventh instars cut the plants off at or just below the soil surface. If the soil is dry and crusted, the larvae remain below the surface and drill into the base of the plant. If the growing point is destroyed or the plant is cut below the growing point, the plant will not survive. Large numbers of black cutworms can drastically reduce the plant population in a field.

After the larvae finish feeding, they pupate. The

moths then emerge from the soil and begin mating and laying eggs for the next generation. There may be three or four generations each year, but the later generations rarely injure taller corn.

Although some growers apply soil insecticides to prevent an infestation of black cutworms, this practice usually is not justified economically. Because black cutworm populations are so sporadic and difficult to predict, a wait-and-see approach to cutworm management is recommended.

Field monitoring is the key to effective management of black cutworms. To determine the need for a rescue treatment, scout during plant emergence, particularly those fields considered to be at high risk. Check the field for leaf feeding, cut plants, wilted plants, and missing plants. A rescue treatment may be warranted if 3 percent or more of the plants are cut and cutworms are still present. A single cutworm will cut three or four plants if the plants are in the two-leaf stage or smaller. After corn plants reach the four-leaf stage, a single cutworm will cut only one or two plants during the remainder of its larval stage.

Control of cutworms may be poor regardless of the insecticide used if the topsoil is dry and crusted and the worms are feeding below the soil surface. Cutworm control may be enhanced by cultivating or running a rotary hoe over the field before or after spraying. This disruption causes the worms to move around and come into contact with the insecticide. Insecticides registered for control of black cutworms are presented in Table 17.02.

Corn rootworms. Corn rootworms are the most economically important pests of corn in Illinois. The corn rootworm complex includes three species: western, northern, and southern corn rootworms. Southern corn rootworms do not overwinter in the Midwest, however, so the western and northern species are the only injurious species in Illinois.

The background color for both male and female western corn rootworms is yellow-tan, but the two sexes differ somewhat in their markings. On males, nearly the entire front half of each wing cover is black; only the tips of the wing covers are yellow-tan. Females are slightly larger and have three distinct black stripes on the wing covers, one near each outer edge and one in the middle. Northern corn rootworms have no distinct markings. Newly emerged northern corn rootworms are cream or tan in color, but they become green as they age. Both species are about ¼-inch long. The larvae of both species are creamy white with a brown head and tail plate.

Western and northern corn rootworms overwinter as eggs in the soil. Eggs begin hatching in May. If corn has been planted in the field, the larvae feed on the roots. Rootworms survive only on the roots of corn and a few grasses. They cannot survive on the roots of soybeans and other broadleaf plants.

Larvae chew on and tunnel inside or along the roots. As they feed, the larvae prune roots back to the stalk. Extensive feeding weakens the root systems. Injured plants cannot take up water and nutrients efficiently and are susceptible to lodging. Yield losses are a result of both root pruning and lodging.

When the larvae finish feeding, they pupate within small earthen cells. The pupa transforms into the beetle stage in about one week, and beetles begin emerging in late June or early July.

Rootworm beetles will feed on corn leaves and weed blossoms, but they prefer corn silks and pollen. They clip fresh, green silks off at the ear tip, an injury that may interfere with pollination, so some kernels never form. An average of 5 or more beetles per plant is usually sufficient to cause economic damage if they are clipping silks to within ½-inch of the ear tip.

Beetles mate in July and August, and the females lay eggs almost exclusively in cornfields in the top 4 inches of soil. Western and northern corn rootworms complete one generation each year.

A corn-soybean rotation usually provides excellent control of rootworm larvae because the larvae survive only on corn roots; rootworm beetles do not lay many eggs in soybeans; and rootworms complete only one generation each year. A corn-soybean rotation may fail to control rootworms when volunteer corn plants in a soybean field attract egg-laying beetles or when rootworms exhibit prolonged diapause, a biological phenomenon that allows some rootworm eggs, primarily those of northern corn rootworms, to remain dormant in the soil for more than one winter. However, the occurrence of this trait is infrequent and rarely contributes to economic damage in a corn-soybean rotation.

Corn planted after corn is susceptible to injury by corn rootworm larvae, depending upon the size of the rootworm population. Most producers who grow corn after corn usually apply a soil insecticide at planting time to protect the corn roots from larval feeding injury. Most growers apply granular insecticides in either a 7-inch band directly over the row or directly into the seed furrow (Table 17.02 and Table 17.03). Some liquid formulations of soil insecticides are also labeled for control of corn rootworm larvae (Table 17.02 and Table 17.03).

By counting western and northern corn rootworm beetles from mid-July into September, growers can figure out the potential for rootworm larval injury the following year. If the average is 0.75 or more beetles per plant for any sampling date, plan to rotate to a nonhost crop, or apply a rootworm insecticide if corn will be planted the following year. If the average is fewer than 0.75 beetle per plant, the probability of economic damage the next year is low, and a soil insecticide is not necessary.

Another corn rootworm management tactic is to control the beetles in July or August or both months to prevent them from laying eggs. If this tactic works, a soil insecticide is not needed the following year, even if corn is planted after corn. Both conventional insecticides and insecticide baits are used to control the beetles before they lay eggs. However, the prerequisites

Table 17.03. Soil Insecticides for Rootworm Control in Illinois, 1995

Insecticide	Time of application	Oz of product per 1,000 ft of row	Amount of product per acre[a]			
			40″ rows	38″ rows	36″ rows	30″ rows
•Counter 15G	At planting or cultivation	8	6.5 lb	6.9 lb	7.3 lb	8.7 lb
Counter CR	At planting or cultivation	6	4.9 lb	5.2 lb	5.4 lb	6.5 lb
Dyfonate II 15G	At planting or cultivation	8	6.5 lb	6.9 lb	7.3 lb	8.7 lb
•Dyfonate II 20G	At planting or cultivation	6	5.0 lb	5.2 lb	5.4 lb	6.5 lb
•Force 1.5G	At planting	8-10	6.5-8.2 lb	6.9-8.6 lb	7.3-9.1 lb	8.7-10.9 lb
•Force 3G	At planting	4-5	3.3-4.1 lb	3.4-4.3 lb	3.6-4.5 lb	4.4-5.5 lb
•Furadan 4F	At planting or cultivation	2.5 fl oz	2 pt	2⅛ pt	2¼ pt	2¾ pt
•Holdem 20G	At planting or cultivation	6	5 lb	5.2 lb	5.4 lb	6.5 lb
Lorsban 15G	At planting or cultivation	8	6.5 lb	6.9 lb	7.3 lb	8.7 lb
Lorsban 4E	At cultivation	2.5 fl oz	2 pt	2⅛ pt	2¼ pt	2¾ pt
•Thimet 15G	At planting or cultivation	8	6.5 lb	6.9 lb	7.3 lb	8.7 lb
•Thimet 20G	At planting or cultivation	6	4.9 lb	5.2 lb	5.4 lb	6.5 lb

• Use restricted to certified applicators only.
[a] Do not exceed the following amounts of specific products per acre per season: 8.7 lb of Counter 15G; 6.5 lb of Counter CR; 27 lb of Dyfonate II 15G; 20 lb of Dyfonate II 20G; 13.5 lb of Lorsban 15G. The minimum row spacing of corn to which Holdem 20G, Thimet 15G, and Thimet 20G can be applied is 30 in.

for a successful beetle suppression program are complex. It is necessary to identify both species (western and northern), distinguish between the sexes, and determine whether the females are ready to lay eggs. Frequent scouting trips and precise scouting techniques are also required.

Planning your rootworm management program. A management plan for rootworms should be long-range (not a year at a time) and include crop rotation, insecticide rotation, cultivator treatments, and scouting to determine the need for rootworm control.

- Alternate corn with another crop when possible, particularly in fields where rootworm beetles averaged 0.75 or more per plant last summer, or if the soil insecticide did not adequately protect the roots during the previous growing season.
- If the plan is to grow corn after corn and if rootworm beetles averaged 0.75 or more per plant in corn after corn or 0.5 per plant in first-year corn last summer, apply a rootworm soil insecticide at planting time.
- Consider a cultivation-time application of a rootworm soil insecticide if the intent is to plant in early April or if the planned planting-time insecticide does not provide adequate root protection.
- Scout for rootworm beetles from mid-July through early September to determine the potential for rootworm larval damage for the next growing season.

Other soil insects in corn. In addition to corn rootworms and black cutworms, several other insects attack the underground portions of the corn plant early in the season. Wireworms and seedcorn maggots occasionally injure seeds and seedlings. White grubs and grape colaspis larvae feed on the roots. Other insects — including billbugs, other species of cutworms, and webworms — feed on corn seedlings at or just above or below the soil surface.

Wireworms. Most wireworm larvae are yellowish or reddish brown, hard-shelled, and wirelike. However, one "soft-bodied" species is creamy white except for its reddish brown head and tail section. Wireworms attack the seed or drill into the base of the stem below ground, damaging or killing the growing point. Aboveground symptoms are wilted, dead, or weakened plants and spotty stands. Several species of wireworms attack corn, and they may live for 2 to 5 years in the larval stage.

The adults (click beetles) prefer to lay eggs in grassy fields or small-grain stubble. Injury in a field in a particular year can usually be attributed to the condition of the field two to four years earlier when the beetles were laying eggs. Fields with a corn–soybean–small-grain rotation and fields of corn planted after sod have the greatest potential for wireworm damage.

Although wireworm infestations are difficult to predict, solar bait stations will trap wireworm larvae early in the spring. Establish bait stations by placing a mixture of corn and wheat seed in a 4- to 6-inch hole in the ground, covering the seeds with soil, then covering the soil with plastic. The plastic warms the soil and induces germination. Wireworm larvae are attracted to the germinating seeds. After the baits have been in the ground for 10 to 14 days, dig them up and count the wireworms. An average of one or more wireworms per bait station suggests that an economically damaging population is present in the field. The grower can apply a soil insecticide that controls wireworms.

White grubs. Economically important white grubs have 3-year life cycles. Peak levels of injury usually occur during the year following large flights of May beetles, the adult stage of white grubs. The beetles prefer to lay eggs in ground covered with vegetation, for example, weedy soybean fields and sod.

The C-shaped white grub has a brown head and is

about an inch long. The grubs chew on the roots and root hairs. Symptoms of white grub injury visible above ground are irregular emergence, reduced stands, and stunted or wilted plants. Injured plants often cannot take up phosphorus efficiently, so the plants may turn purple. Injury is generally spotty throughout the field.

Rescue treatments applied after injury caused by wireworms or white grubs has been observed are ineffective. An insecticide seed treatment protects the seed from attack by wireworms but does not protect the seedling plant from wireworms and white grubs.

Several soil insecticides are registered for the control of wireworms and white grubs (Table 17.02). The percentage of fields affected in Illinois is so small, however, that the widespread use of soil insecticides to prevent injury by these pests is not justified economically.

European corn borer. The European corn borer is one of the most destructive pests of corn in the United States. The larvae tunnel inside the corn plants and disrupt the flow of water and nutrients to the developing ear. Extensive tunneling may cause stalks to break or lodge. Tunneling in the ear shank may result in ear drop. Corn borer feeding also provides an avenue into the plant for infection by stalk rot organisms.

Corn borer larvae are cream- to flesh-colored, with small, raised, dark spots (tubercles) on each body segment. The head is dark brown. Full-grown larvae are ¾- to 1-inch long. The female moth is buff-colored, with wavy, olive-brown bands on the wings and a wingspan of an inch. The male moth is slightly smaller and darker than the female.

Two or three generations of European corn borers occur every year, depending upon the location in the state and the weather. The third generation is most common in southern Illinois. European corn borers overwinter as mature larvae, usually inside the stalk. Spring development starts when temperatures exceed 50°F. The larvae begin pupating in May, spend about two weeks in the pupal stage, and emerge as moths in late May and June.

Moths laying eggs for the first generation seek the tallest (earliest planted) corn. The female lays eggs in masses on the undersides of corn leaves near the midrib. Each mass contains fifteen to thirty eggs that are flat and overlapping like the scales of a fish. During development, the eggs change from white to a creamy color. Immediately before hatching, the black heads of the larvae are visible through the shells.

After the eggs hatch, the tiny larvae begin to feed on the leaf surfaces and move into the whorl, where their feeding causes "shot holes" in the leaves. By the third stage (instar) of development, the larvae begin tunneling into the leaf midribs; the fourth and fifth (last) stages bore into the stalks. When they finish feeding, the larvae pupate inside the stalk. Transformation to the adult (moth) stage occurs within the pupa, then the moths emerge to mate and lay eggs to initiate the next generation. Corn borers require three to four weeks to develop from egg to adult.

Moths laying eggs for the second generation seek later-maturing fields with fresh pollen and silks. They usually deposit their eggs on the undersides of leaves between the ear zone and the tassel. Newly hatched larvae feed primarily on pollen that accumulates in the leaf-collar areas. More mature larvae tunnel into the stalks, ear shanks, and ears.

Injury to corn by first-generation larvae is primarily physiological. The yield loss caused by this generation is a result of interference with the transport of nutrients and water in the stalk and leaves. Injury by the second generation is both physiological and physical. Most of the yield loss is caused by second-generation corn borers feeding in the stalks from just before pollination until the ears are filled. Stalk breakage, ear feeding, and ear drop also contribute to yield reduction. Physical damage is amplified when stalk rot weakens the plant.

Scout for first-generation corn borers and injury during June. The percentage of plants with whorl feeding and the average number of larvae per infested plant are critical. Borers can be located by unrolling the whorls of several plants.

Scout for second-generation corn borers by counting egg masses. Start checking when moth flight is under way, usually from July through mid-August.

Entomologists have developed management worksheets for both first- and second-generation European borers to aid in making decisions about control. See the worksheet provided. The level of infestation (obtained from scouting), the expected yield, the anticipated value of the grain, and the cost of control are required to complete the worksheet. Enter these data into the worksheet to calculate the gain or loss if an insecticide is applied.

For the most effective corn borer control, apply treatments soon after egg hatch to kill the young larvae before they bore into the plant. The larvae begin tunneling into stalks about 10 days after hatching.

Fall plowing and shredding stalks significantly reduce the number of corn borers that overwinter within a given field. However, there will be little effect on the likelihood of borer injury the following year if nearby fields are not shredded or plowed. European corn borer moths are mobile and can fly as far as 5 miles in a night. Moths that emerge from fields not shredded or plowed may fly to nearby fields to lay eggs, especially if the nearby fields were planted earlier. As a consequence, fall plowing or stalk shredding will not guarantee a reduction in corn borer problems in individual fields.

Although most of the hybrids planted in Illinois are susceptible to attack by corn borers, some are resistant to first-generation corn borers, and others have some degree of tolerance to borer injury. As a first step in managing European corn borers, growers are advised to select varieties that are resistant or tolerant.

Management Worksheet for
First-Generation Corn Borer

________ % of 100 Plants Infested x ________ Average No. Borers/Infested Plant = ________ Borers/Plant
(determined by checking whorls from 10 plants)

________ Borers/Plant x ________ % Yield Loss/Borer* = ________ % Yield Loss

________ % Yield Loss x ________ Expected Yield (Bu/acre) = ________ Bu/acre Loss

________ Bu/acre Loss x $ ________ Price/Bu = $________ Loss/acre

$________ Loss/acre x ________% Control = $________ Preventable Loss/acre
(80% for granules)
(50% for sprays)

$________ Preventable Loss/acre − $________ Cost of Control/acre =

$________ Gain (+) or Loss (−) per acre if treatment is applied

* 5% for corn in the early whorl stage; 4% (late whorl); 6% (pretassel).

Management Worksheet for
Second-Generation Corn Borer

________ Number of Egg Masses/Plant x 4 Borers/Egg Mass* = ________ Borers/Plant
(cumulative counts, taken 7 days apart)

________ Borers/Plant x ________ 3% Yield Loss/Borer** = ________ % Yield Loss

________ % Yield Loss x ________ Expected Yield = ________ Bu/acre Loss

________ Bu/acre Loss x $ ________ Price/Bu = $________ Loss/acre

$________ Loss/acre x __75__% Control = $________ Preventable Loss/acre

$________ Preventable Loss/acre — $________ Cost of Control/acre =

$________ Gain (+) or Loss (−) per acre if treatment is applied

* Assumes survival rate of 20 percent (4 borers/egg mass).
** 5% for corn in the early whorl stage; 4% (late whorl); 6% (pretassel); 4% (pollen shedding); 3% (kernels initiated). Use 3% per borer per plant if infestation occurs after silks are brown. The potential economic benefits of treatment decline rapidly if infestations occur after corn reaches the blister stage.

Insect pests of soybeans

Although many insects and mites feed on soybeans, annual problems with insects and mites are infrequent in Illinois. Only a few reach outbreak proportions in Illinois, usually in conjunction with extreme weather patterns. Twospotted spider mites caused serious yield reductions during the drought of 1988, for example.

Some of the most common insect pests are defoliators, including bean leaf beetles, blister beetles, grasshoppers, green cloverworms, Japanese beetles, thistle caterpillars, webworms, and woollybear caterpillars. General economic thresholds have been established for these pests. Soybeans can tolerate considerable defoliation without yield reduction, although tolerance

to defoliation depends upon the stage of plant growth and stress to the plant. While the plants are growing and producing new leaves, and again after the seeds are completely filled, soybeans can withstand considerable leaf-feeding injury. Defoliation must exceed 30 to 40 percent before yield is affected. Soybean plants are more susceptible to yield-reducing injury during the blooming and pod-filling stages, so the economic threshold during these stages is 20 percent defoliation.

A few pests of soybeans suck fluids from the plants: potato leafhoppers, spider mites, and thrips. Of these, only spider mites are capable of being a serious threat. Some insects, like cutworms, grape colaspis, and seedcorn maggots, attack the underground parts of soybean plants. Pod feeders include bean leaf beetles, corn earworms, grasshoppers, and stink bugs.

Bean leaf beetle. Bean leaf beetles are about ¼-inch long, with considerable variation in color pattern. The background color may be yellow, green, tan, or red. Most beetles' wing covers have four black spots and black stripes along the edges, although these markings may be absent. A black triangle is always present at the base of the wing covers just behind the prothorax, the "neck" area between the head and wing covers.

The beetles overwinter under debris in protected areas. When temperatures warm in the spring, the beetles fly into alfalfa and clover fields to feed but do not lay eggs there. As soon as soybeans begin emerging, the beetles abandon alfalfa and clover fields to colonize soybean fields. They feed on the cotyledons, leaves, and stems of emerging soybeans and lay eggs in the soil. The eggs hatch in a few days, and the larvae feed on the roots and nodules of the plants. The larvae are white, with dark-brown areas at both ends. When the larvae finish feeding, they pupate.

Adults of the first generation begin to emerge in July, but the peak occurs in late July or early August. The beetles feed on the soybean foliage, leaving small holes in the leaves. If the infestation is severe, soybean plants may be completely riddled with holes.

The beetles again lay eggs in soybean fields, and a second generation occurs. Adults of the second generation begin emerging in September. They do not lay eggs, but they remain in the soybeans as long as there are tender plant parts on which to chew. They may chew on pods after the leaves become old, and their feeding creates scars that provide an avenue of infection for certain plant pathogens. Mild infection results in seed staining; severe infection results in seed contamination. As the temperature decreases, the beetles seek overwintering sites in wooded areas.

Monitoring for bean leaf beetles should begin when soybean seedlings emerge and resume when first-generation adults are feeding on the leaves in July and August. The seedling stage and the pod-filling stage are the two most critical stages of growth. Treatment may be justified if at least one seedling per foot of row is destroyed, or when 20 percent of the plants are cut and the stand has gaps of a foot or more. This level of damage usually requires 5 or more beetles per foot of row. An insecticide spray is economically justified during the pod-filling stage if defoliation exceeds 20 percent and there are 16 or more beetles per foot of row. The economic threshold for beetles that are damaging pods is 10 or more beetles per foot of row and 5 to 10 percent injured pods.

Pod feeders. Bean leaf beetles, corn earworms, grasshoppers, and stink bugs may injure soybean pods in Illinois; however, the occurrence of corn earworms in soybeans in Illinois is infrequent.

Bean leaf beetle. The last generation of bean leaf beetles to emerge chews on soybean pods after the leaves become too old. The beetles scrape off the green tissue on the pods but do not chew through the pod wall. The resulting scars on the pods provide an avenue for entry of spores of various fungal diseases that are normally blocked by the pericarp. Mild infection results in seed staining; severe infection results in total seed contamination.

Grasshopper. Grasshoppers cause more direct injury to the soybean seeds. Because they are equipped with strong chewing mouthparts, grasshoppers often chew through the pod wall and take bites out of or devour entire seeds. If more than 5 to 10 percent of the pods are injured by grasshoppers or bean leaf beetles, an insecticide application may be warranted.

Stink bugs. Green stink bugs are believed to migrate northward from overwintering sites (wooded areas under leaf litter) as adults. During the early months of summer, the adults feed on berries in trees, especially dogwoods. Stink bugs are first found in soybean fields during August. They undergo incomplete metamorphosis (immature bugs resemble the adults), which requires approximately 45 days from egg hatch to adult emergence. There is usually only one generation of green stink bugs per year in Illinois.

Immature stink bugs (nymphs) have a flashy display of black, green, and yellow or red colors and short, stubby, nonfunctional wing pads. The adults are large (about ⅝-inch long), light-green, shield-shaped bugs with fully developed wings. Both adults and nymphs have piercing and sucking mouthparts for removing plant fluids.

Stink bugs feed directly on pods and seeds; however, their injury is difficult to assess because their piercing, sucking mouthparts leave no obvious feeding scars. Stink bugs use their mouthparts to penetrate pods and puncture the developing seeds. They inject digestive enzymes into seeds, and the feeding wound provides an avenue for diseases to gain entry into the pod. Seed quality is also reduced by stink bug feeding, and beans are more likely to deteriorate in storage. An insecticide application for control of stink bugs may be warranted when the level of infestation reaches 1 adult bug or large nymph per foot of row during pod fill.

Other species of stink bugs also occur in soybeans. The brown stink bug has feeding habits and biology similar to those of the green stink bug. The brown

stink bug should not be confused with the beneficial spined soldier bug. These two species can be distinguished from each other if you look at the feeding beak and underside of the abdomen. The beak of the brown stink bug is slender and embedded between the lateral parts of the head. The base of the beak of the spined soldier bug is stout and free from the lateral parts. In addition, the spined soldier bug has a dark round spot located centrally on the underside of its abdomen (belly). Be aware of the species present in a soybean field before making a control decision.

Spider mites. The most common mite species found in soybean fields in Illinois is the twospotted spider mite. These tiny mites (0.002 inch), related to spiders, have four pairs of legs in the adult stage and range in color from pale yellow to brown.

Spider mites hatch from very small eggs. Larvae with six legs emerge from the eggs and progress through two nymphal stages, each with eight legs. After the last nymphal molt, the eight-legged adults emerge. Spider mites complete a generation in 1 to 3 weeks, depending on environmental conditions (primarily temperature).

Spider mites may be blown into soybean fields or carried in by equipment or animals. They also crawl from weed hosts to soybean plants, so infestations usually appear first along field edges or in spots within a field. Mites can move throughout fields by "ballooning," that is, by spinning webs and moving to a position on a leaf from which they can be blown aloft. They can also move from row to row by bridging (moving across leaves in contact) when the canopy is nearly closed.

Spider mites have piercing, sucking mouthparts with which they puncture plant cells and remove plant juices. Damaged plant cells do not recover. Initial injury results in a yellow speckling of the leaves. Heavy infestations cause leaves to wilt and die. Another sign of the presence of spider mites is the webbing they produce on the undersides of the leaves.

Outbreaks of spider mites are associated with hot, dry weather; populations usually peak by mid- to late season. If the soybeans have an adequate supply of moisture, the mites usually do not cause any economic damage.

A miticide for control of spider mites might be warranted when 20 to 25 percent discoloration is noted before pod set or when 10 to 15 percent discoloration is noted after pod set. Watch field margins closely for symptoms of mite injury as early as late June, but especially during late July and August. Confining the miticide application to border rows and other areas of confirmed infestation is recommended.

Insect pests of wheat

In Illinois, few insects attack wheat. However, when outbreaks of insects coincide with the head-filling stage of wheat growth, yield losses can be serious. Most of the potential pests are defoliators, such as armyworms and cereal leaf beetles, that may cause extensive injury to the flag leaves. Other pests include Hessian flies and several species of aphids.

Armyworm. The armyworm feeds on several field and forage crops. Armyworms prefer grasses and grain crops such as wheat and corn but occasionally can be found in forage legume crops.

Newly hatched larvae are pale green with longitudinal stripes and a yellow-brown head. Fully grown larvae are about 1½ inches long and green-brown, with two orange stripes on each side. Several longitudinal stripes mark the remainder of the body. Each proleg (the false, peglike legs on the abdomen of a caterpillar) has a dark band. The moth is tan or gray-brown and has a 1½-inch wingspan. A small white dot in the center of each forewing is a distinguishing mark.

Few armyworms overwinter in Illinois, but some partly grown larvae probably survive the winter under debris in southern counties. Pupation occurs in April; the moths emerge and begin laying eggs in May. Moths that migrate from southern states into Illinois add to the resident population.

Moths prefer to lay eggs on grasses or grains. The eggs hatch in about a week, and the larvae begin to feed on foliage. Young larvae scrape the leaf tissues; older larvae feed from the edges of the leaves and consume all of the tissue. Larvae feed only at night or on cloudy days. After feeding, the larvae pupate under debris or in the soil, and the moths emerge to begin another cycle. There are two or three generations each year in Illinois.

Armyworm moths may lay numerous eggs in wheat fields, and the larvae feed until the grain matures or the wheat is harvested. The larvae feed on the leaves, working their way up from the bottom of the plants. Injury to the lower leaves causes no economic loss, but injury to the upper leaves, especially the flag leaf, can result in yield reduction. After armyworms devour the flag leaves, they often chew into the tender stem just below the head, causing the head to fall off. After the grain matures or is harvested, the larvae will migrate into adjacent cornfields. Large numbers of larvae can destroy corn plants within a day or two.

Early detection of an armyworm infestation is essential for effective management. Examine dense stands of wheat for larvae. If the number exceeds 6 nonparasitized worms ¾ to 1¼ inches long per foot of row, an insecticide may be justified.

Weather and natural enemies are the major causes of reductions in armyworm numbers. Hot, dry weather promotes the development of parasitoids and diseases, reducing populations of armyworms. Cool, wet weather is most favorable for an outbreak.

Cereal leaf beetle. Cereal leaf beetles annually cause some injury to wheat in southern and central Illinois. Mild winters and lush fall growth create excellent overwintering conditions for the beetles.

The cereal leaf beetle adult is hard-shelled and about $\frac{3}{16}$-inch long. Its wing covers and head are

metallic blue-black, while its legs and the front segment of its thorax (just behind the head) are red-orange. The larva is slightly longer than the adult and resembles a slug. Its skin is yellow to yellow-brown, but the larva carries a moist glob of fecal material on its back that makes it look black.

Adults overwinter in clusters in sheltered areas. In the spring, the beetles fly to fields of winter wheat and other small grains. When spring oats emerge, the beetles quickly infest the young plants. They feed for about 2 weeks before they lay eggs. Eggs usually hatch in 5 days, and the larvae grow and feed for about 10 days. After they finish feeding, the larvae descend to the ground and pupate in the soil. New beetles emerge after 2 to 3 weeks. These beetles often fly to the edges of cornfields and feed on the leaves. After feeding for about 2 weeks, the beetles enter summer hibernation.

The larvae eat only the surface of wheat leaves, so injured plants are silvery in appearance. Severely damaged fields appear frosted. Yield losses occur when the larvae feed on the flag leaves. Control may be warranted when the combination of eggs and larvae average 3 or more per stem or there is an average of 1 or more large larvae per stem.

Adults eat longitudinal slits between the veins; they eat completely through the leaves of both wheat and corn. Corn plants usually recover from this injury.

Chapter 18.

Disease Management for Field Crops

Successful management of field crop diseases that are found in Illinois is based on a thorough understanding of factors influencing disease development and expression. Strategies should include measures to reduce losses in the current crop as well as considerations for future plantings.

The interaction of four factors influences the development of all plant diseases: (1) the presence of a susceptible host crop; (2) a pathogen (disease-causing agent) capable of colonizing the host; (3) an environment that favors the pathogen and not the host; and (4) adequate time for economic damage and loss to occur. All plant disease management is directed toward disrupting one or more of these factors.

Among measures used to manage plant diseases are crop rotation, genetic resistance, fungicides, and cultural (agronomic) practices. The success of these measures is dependent upon how carefully crops are scouted and diseases assessed. Regular scouting of crops increases the likelihood that disease management will be properly applied and can reduce the unnecessary use of pesticides. Pesticides are best used only when there is threat of an epidemic deemed uncontrollable through the use of other measures.

Fungicides

Fungicide application

At present, aircraft are the best vehicles for applying foliar fungicides to agronomic crops. Some aircraft may not be equipped or calibrated to do this job. It is therefore important to select an aerial applicator who is familiar with disease control and whose aircraft has been properly calibrated for uniform, thorough coverage of all above-ground plant parts. With the equipment now available, a reasonable job of applying fungicides requires a minimum of 5 gallons of water carrier per acre. Superior coverage may be obtained with more water, but the cost may be prohibitive. Conversely, a lower volume (less than 3 to 4 gallons per acre) gives correspondingly poorer control. Five gallons of water can be applied uniformly using about thirty to seventy properly spaced nozzles, depending on the aircraft. The nozzles should be D-8 to D-12, hollow cone, with No. 45 or No. 46 cores. The final decision on nozzle number, size, swath width, and placement depends on the air speed, pressure, and volume desired. Droplet size is also important. Ideally, droplets should be 200 to 400 microns in size for thorough and uniform coverage.

Use of adjuvants

When it is compatible with the product label, the addition of a spray adjuvant (surfactant) to the spray mix is suggested. Adjuvants can help disperse fungicides and improve coverage when spraying. They are especially helpful for corn and small grains.

Nematicide application

Granular nematicides/insecticides registered for use on corn, sorghum, and soybeans may be used as in-furrow or band treatments, depending on the product label. In general, band applications have given more consistent control than have in-furrow applications. Follow the manufacturer's suggestions on incorporation. Nematicides are not designed to replace crop rotation and the use of resistant crop varieties in a management program. Successful nematode management is based upon a combination approach that may include pesticides. However, pesticides alone will not provide adequate control and may produce additional environmental problems.

Fungicide guidelines

Seed treatments. The greatest benefits of fungicide seed treatments will be found (1) where low seeding

rates are used; (2) where seed must be used that is of poor quality because of fungal infection; and (3) where seed is planted in a seedbed in which delays in germination or emergence are likely.

Fungicide seed treatments are not a substitute for high-quality seed and will not improve the performance of seed that is of low quality due to mechanical damage or physiological factors. Treated seed of low quality will not produce stands and/or yields equal to untreated high-quality seed. Therefore, only high-quality seed should be considered for planting.

Disease management of specific crops

Although disease management recommendations will vary depending upon the host crop, many of the techniques are applicable to all field crops. For specific disease control recommendations, consult the current edition of the *Illinois Agricultural Pest Management Handbook* and other chapters within this publication.

Integrated pest management

Alfalfa disease management

Alfalfa is subject to a number of seedling blights, root and crown rots, and leaf blights. Losses can be minimized by an integrated management approach which includes:

1. Growing winterhardy, disease-resistant varieties.
2. Planting high-quality, disease-free seed produced in an arid area.
3. Providing a well-drained, well-prepared seedbed.
4. Using crop rotation with nonlegumes.
5. Cutting in a timely manner to minimize losses to foliar blights.
6. Using proper fertilization practices and maintaining the proper pH.
7. Avoiding cutting or overgrazing during the last five or six weeks of the growing season.
8. Controlling insects and weeds.
9. Cutting only when foliage is dry.
10. Destroying unproductive stands.
11. Following other suggested agronomic practices.

Table 18.01 lists the most common diseases in Illinois and the effectiveness of various management methods. No control measures are necessary or practical for several of the common alfalfa diseases, including bacterial blight or leaf spot, bacterial stem blight, downy mildew, and rust. For other diseases, producers should select resistant varieties. Specific variety recommendations are found in this handbook in Chapter 8, "Hay, Pasture, and Silage."

Disease-resistant varieties. Resistance to bacterial wilt, Fusarium wilt, Verticillium wilt, common leaf spot, Lepto (pepper) leaf spot, spring black stem, anthracnose, and Phytophthora root rot is available in many newer varieties. However, no variety is resistant to all common diseases. Alfalfa producers should identify the common pathogens in their areas and select varieties according to local adaptability, high-yield potential, and resistance to these common pathogens.

Planting site and crop rotation. The choice of planting site often determines which diseases are likely to occur because most pathogens survive between growing seasons on or in crop debris, volunteer alfalfa, and alternate host plants. Pythium and Phytophthora seedling blights, for example, are more common in heavy, compacted, or poorly drained soils and survive in infected root tissues. Leaf blighting fungi survive in undecayed leaf and stem tissues. These pathogens die out once residues decay.

Other pathogens are dispersed by wind currents and can be found in almost any field. Alfalfa mosaic viruses are transmitted by aphids that may be blown many miles. Thus, planting site selection alone will not ensure a healthy crop.

Rotating crops. The diseases strongly associated with continuous alfalfa production include bacterial wilt, anthracnose, a variety of fungal crown and root rots, Phytophthora root rot, Fusarium wilt, Verticillium wilt, spring and summer black stem, common and Lepto leaf spots, bacterial leaf spot, and Stagnospora leaf and stem spot. Rotating crops and using tillage to encourage residue decomposition before the next alfalfa crop is planted will help reduce the incidence of many diseases.

Since most alfalfa pathogens do not infect plants in the grass family, rotation of two to four years with corn, small grains, sorghum, and forage grasses will help reduce disease levels.

Cutting of alfalfa in the mid- to late-bud stage. Cutting heavily diseased stands before bloom and before the leaves fall will maintain the quality of the hay and remove the leaves and stems that are the source of infection (primary inoculum) for later disease. This will help ensure that succeeding cuttings have a better chance of remaining healthy. Cutting in the mid- to late-bud stage, harvesting at 30- to 40-day intervals, and cutting the alfalfa short are practices that help to control most leaf and stem diseases of alfalfa.

Cutting only when the foliage is dry. This practice minimizes the spread of fungi and bacteria that cause leaf and stem diseases, wilts, and crown and root rots.

Controlling insects. Insects commonly provide wounds by which wilt, crown- and root-rotting fungi, and bacteria enter plants. Insects also reduce plant vigor, increasing the risk of stand loss from wilts and root and crown rots.

Controlling weeds. Do not allow a thick growth of weeds to mat around alfalfa plants. Like rank, tall plant growth, weeds also reduce air movement; they slow the drying of the foliage and lead to serious crop losses from leaf and stem diseases. Seedling stands under a thick companion crop, such as oats, are commonly attacked by leaf and stem diseases. Weeds also may harbor viruses that can be transmitted to alfalfa by the feeding of aphids. Keep down broadleaf

Table 18.01. Alfalfa Diseases That Reduce Yields in Illinois and the Relative Effectiveness of Various Control Measures

Disease	Planting winter-hardy, resistant varieties	Using high-quality seed	Having a well-drained soil; pH 6.5 to 7	Employing correct crop rotation	Achieving adequate, balanced fertility	Cutting in mid- to late-bud stage	Avoiding late cutting and planting	Avoiding rank growth and high stubble	Maintaining insect and weed control
Bacterial wilt	1		2	3	3	3			3
Dry root and crown rots, decline	3	3	2	2	2		2	3	2
Phytophthora root rot	1		2	2	3		2		
Fusarium wilt	1		3	2	3		2	3	3
Verticillium wilt	1	2			3		3		
Anthracnose	1		3	1	2			2	3
Spring black stem	1	2	3	1	3	2		2	3
Summer black stem		2	3	2	3	2		2	3
Common or Pseudo-peziza leaf spot	1		3	2	2	2		2	3
Stemphylium or zonate leaf spot	3	2		2	3	2		2	3
Lepto or pepper leaf spot	2		3	2	3	2		2	3
Yellow leaf blotch		2	3	2	2	2		2	3
Stagnospora leaf and stem spot			3	2	3	2		2	3
Rhizoctonia stem blight		2	2		2	2		2	3
Seed rot, seedling blights, damping-off		1	2	3	2				3
Sclerotinia crown and root rot	2	3	2	2	2	3	2	2	2
Mosaics		3							2

NOTE: 1 = Highly effective control measure; 2 = Moderately effective measure; and 3 = Slightly effective measure.

weeds in fence rows, drainage ditches, along roadsides, and in other waste areas. Such places serve as a source of mosaic viruses. Whenever possible, do not grow alfalfa close to other legumes — especially clovers, garden peas, and beans. Many of the same viruses that infect alfalfa also attack these and other legumes.

Soybean disease management

Soybean disease management is based upon an integrated system using resistant varieties, crop rotation, tillage (where feasible), fungicides, balanced soil fertility, high-quality seed, scouting, and proper insect and weed control. The use of several of these management practices will help disrupt the combination of factors necessary for disease development. Table 18.02 summarizes the effect of these practices.

Variety selection. All soybean disease management programs should begin with the selection of a variety with resistance to the most common pathogens in the area. Many high-yielding public and private soybean varieties are available with resistance to important diseases such as Phytophthora root rot, soybean cyst nematode, and brown stem rot. Other, less important diseases can also be controlled with resistant varieties. See Chapter 3 in this handbook for more information on variety selection.

One major concern for soybean producers is the possible appearance of new or unexpected *races* of a pathogen, particularly for Phytophthora root rot (PRR) or the soybean cyst nematode (SCN). A race is simply a pathogen population with the ability to infect and colonize a normally resistant host plant. Thus, growers lose the expected protection of the resistance genes and essentially have "susceptible" plants. Different races are known to occur in Illinois for both PRR and SCN. If growers experience losses in fields where resistant varieties are planted and other causes can be ruled out, an unusual pathogen race should be suspected.

For Phytophthora root rot, there is the choice of selecting resistant or tolerant seed sources. Resistant soybeans contain one or more genes with resistance to specific races of the pathogen. This type of resistance is active from the time of planting until full maturity. It fails only where unusual races occur that are not controlled by the genes in the plant.

Tolerance provides a broad form of resistance to all races of the pathogen. However, it may not provide the level of protection needed where pathogen population levels are extremely high. The major advantage is the protection against all races. However, tolerance is not active in the early seedling stage, and plants are considered to be susceptible to Phytophthora until one or two true leaves have developed. Therefore, an application of Apron seed treatment or Ridomil in-furrow is advised to protect tolerant varieties in the early season.

Agronomic characteristics affecting disease development. The relative maturity of soybean cultivars can have a dramatic impact on disease development. Early maturing varieties are more commonly damaged by pod and stem blight, anthracnose, purple seed stain, and Septoria brown spot. The longer the time period from maturity to harvest, the greater the like-

Table 18.02. Soybean Diseases That Reduce Yields in Illinois and the Relative Effectiveness of Various Control Measures

Disease	Resistant or tolerant varieties	Crop rotation	Clean plow-down	High seed quality	Fungicides	Other controls and comments
Phytophthora root rot	1				3	Numerous races of the fungus are known. Avoid poorly drained areas and soil compaction.
Pythium, Phytophthora, Rhizoctonia, and Fusarium seedling blights and root rots				1	2	Plant high-quality seed in a warm (55 to 60°F), well-prepared seedbed. Shallow planting may be helpful in establishing uniform, vigorous stands.
Charcoal root rot			2	3		Early planting, deep and clean plowing, balanced fertility, narrow rows, and the avoidance of moisture stress will provide some control. Avoid high seeding rates.
Soybean cyst nematode	1	1	3		1 (nematicides)	Early planting and the elimination of susceptible weeds will aid in control. Avoid moving contaminated soil from field to field by equipment, water, or other means. Crop rotations of three years or more are necessary even when using resistant varieties. Maintain balanced fertility and use nematicides as needed. Soil analysis should be used in decision making.
Pod and stem blight, anthracnose, and stem canker		2	2	1	1	Fungicides are suggested to aid in producing high-quality seed. Grain producers may have higher yields in warm, wet seasons. Plant full-season varieties.
Cercospora leaf blight (purple seed stain), Septoria brown spot, frogeye leaf spot	1	2	2	2	1	These diseases may be more important in narrow-row culture systems and where uncleaned seed is planted.
Bacterial blight, bacterial pustule, wildfire	1	2	2	2		Seed should *not* be saved from fields that are heavily infected with these diseases.
Downy mildew	2	2	2	2		This disease may become more important in narrow-row culture systems. Primarily affects seed quality.
Sclerotinia white mold	2	3	2		?	The effectiveness of fungidice sprays is unknown at this time. Varietal differences are known, but no resistant soybeans have been released.
Powdery mildew	1					
Soybean mosaic, bean pod mottle, and bud blight viruses				2		Plant seed produced in fields with a low incidence of soybean mosaic. Damage from bud blight may be reduced by bordering soybean fields with 4 to 8 rows or more of corn or sorghum. This may be especially helpful where soybean fields border alfalfa or clover fields. Before planting, apply herbicides to kill broadleaf weeds in fencerows, ditch banks, grass pastures, etc.
Brown stem rot	1	1				Rotations of two to three or more years are necessary for control. Soybeans planted as end rows on cornfields aid in carrying over the disease. Early maturing varieties are generally less affected than late-maturing varieties. Resistant varieties act as nonhost crops in rotations.
Sudden death syndrome						See comments for soybean cyst nematode. Early planted or early maturing varieties appear to be more susceptible.

NOTE: 1 = Highly effective control measure; 2 = Moderately effective; 3 = Slightly effective.

lihood of damage by these diseases. However, early maturing varieties are generally less affected by brown stem rot.

Soybean growth habit can also affect disease development. Tall, bushy varieties, for example, are more affected by Sclerotinia white mold than shorter, more compact varieties. However, the shorter varieties may also be more prone to damage by water-splashed pathogens such as Septoria brown spot, pod and stem blight, and purple seed stain. Differences in individual variety resistance may negate the effects of plant height on disease development.

Planting date has an impact on diseases. Early planted beans typically have a greater incidence of seedling blights if not protected by a fungicide. Conditions in early spring favor these pathogens and may delay the rapid emergence of soybeans. Early planting also increases the incidence of sudden death syndrome when compared to later plantings.

Crop rotation and tillage are very important practices in controlling most diseases of soybeans. Practically all soybean pathogens depend on crop residues for overwintering and do not colonize other hosts. Therefore, when crop residues are removed or are thoroughly decayed and/or rotation with nonhosts (corn, sorghum, small grains) is used, pathogen population levels decline.

Programs which promote residue decay through tillage or rotations will help reduce such diseases as pod and stem blight, anthracnose, stem canker, powdery and downy mildew, brown stem rot, Sclerotinia white mold, and soybean cyst nematode.

With the increasing acceptance of reduced and no-till practices, the practice of total residue incorporation is declining. Where residues remain on or near the soil surface, it is important to emphasize all other means of control. The presence of residues does not significantly increase disease levels where resistance and crop rotation are practiced.

Row spacing is another factor that can have an impact on disease. Diseases that thrive in cool, wet conditions typically increase where soybeans are planted in narrow rows. If previous soybean crop residue is also present, earlier and more severe epidemics may occur. Diseases such as downy mildew and Sclerotinia white mold are greatly affected by high humidity levels. Narrow rows increase humidity and also disease levels. If tall beans are also planted, there may be little air circulation within the canopy. Thus, where white mold or downy mildew are problems, wider rows or shorter beans will help reduce disease levels.

Wheat diseases

Wheat disease management is based upon an integrated control program using resistant varieties, high-quality seed, fungicide treatments, proper planting time and site, crop rotation, tillage (where feasible), high fertility, and other cultural practices. A summary of these measures and the diseases controlled are given in Table 18.03.

Disease-resistant varieties. Growing resistant varieties is the most economical and efficient method of controlling diseases. Resistance to stem rust, leaf rust, loose smut, Septoria diseases, powdery mildew, soilborne wheat mosaic, barley yellow dwarf, wheat streak mosaic, and wheat spindle streak (wheat yellow mosaic) is of major importance in Illinois. No single wheat variety is resistant to all major diseases. Thus, varieties should be selected according to their local adaptability, high-yield potential, and resistance to the most common and serious diseases.

High-quality seed. Seed that has been improperly stored (binrun) will lose vigor and may develop problems in the seedling stage that continue throughout the season and result in reduced crop yield and quality. Diseases such as bunt, loose smut, basal glume rot, black chaff, ergot, Septoria diseases, Helminthosporium spot blotch or black point, and scab may be carried with, on, or within the seed.

Planting site. The choice of a planting site often determines which diseases are likely to occur because many pathogens survive on or in crop debris, soil, volunteer wheat, and alternate host plants. This is most important in the control of Septoria leaf and glume blotches, Helminthosporium spot blotch, tan or yellow leaf spot, scab, ergot, take-all, Fusarium and Helminthosporium root rots, crown or foot rots, Cephalosporium stripe, bunt or stinking smut, downy mildew, eyespot or strawbreaker, Pythium and Rhizoctonia root rots, sharp eyespot, soilborne wheat mosaic, and wheat spindle streak mosaic or wheat yellow mosaic. There are other diseases which are not affected by choice of planting site, including airborne and insect-transmitted diseases. These include barley yellow dwarf virus, wheat streak mosaic virus, and rusts.

Crop rotation. Crop rotation is an extremely important means of reducing carryover levels of many common wheat pathogens. Diseases strongly associated with continuous wheat production include take-all, Helminthosporium spot blotch, tan or yellow spot, crown and foot rots, root rots, head blights, Septoria leaf and glume blotches, black chaff, powdery mildew, Cephalosporium stripe, soilborne wheat mosaic, wheat

Table 18.03. Effect of the Form of Nitrogen on Various Wheat Diseases

Disease	Nitrogen form: Nitrate	Nitrogen form: Ammonium
Root and Crown Diseases		
Take-all	Increase	Decrease
Fusarium root rot	Decrease	Increase
Helminthosporium diseases	Decrease	. . .[a]
Foliar Diseases		
Powdery mildew	Increase	. . .[a]
Leaf and stem rust	Increase	Decrease
Septoria leaf blotch	Increase	. . .[a]

[a] = No effect or data not unavailable.

streak mosaic, scab, downy mildew, eyespot and sharp eyespot, ergot, and anthracnose.

With many common wheat diseases, crop debris provides a site for pathogen populations to survive adverse conditions. Many of these pathogens do not survive once crop debris is decomposed. Rotations of two or three years with nonhost crops (such as corn, sorghum, alfalfa, and clovers), coupled with other practices that promote rapid decomposition of crop residue will reduce the carryover populations of these pathogens to very low levels. Soilborne wheat mosaic and wheat spindle streak or wheat yellow mosaic increase when wheat is planted continuously in the same field. To control these diseases, rotations must cover at least six years. Using highly resistant varieties is the best way to control losses from these types of diseases.

Replanting the same field to winter wheat following an early summer harvest does not constitute an adequate rotation.

Tillage. Although a clean plow-down is of great help in disease control, the losses to soil erosion should be carefully weighed against potential disease losses. Pathogens dispersed short distances by wind and splashing water may infect crops early and cause more severe losses where crop debris from the previous wheat crop remains on the soil surface. The need for clean tillage, therefore, is based on the prevalence and severity of diseases in the previous crop, other disease-control practices available, the need for erosion control, rotation plans, and related factors.

If conservation tillage practices are implemented, strict attention must be paid to all other disease control practices.

Fertility. The effect of fertility on wheat diseases is quite complex. Adequate and balanced levels of nitrogen, phosphorus, potassium, and other nutrients — based on a soil test — will help reduce disease losses, particularly from take-all, seedling blights, powdery mildew, anthracnose, and Helminthosporium spot blotch. Research has shown that the level and form of nitrogen both play an important role in disease severity. The severity of certain diseases is decreased by using ammonia forms of nitrogen (urea and anhydrous ammonia) and is increased by using the nitrate forms of nitrogen. In other cases, the reverse is true. The general effect on disease severity caused by the form of nitrogen used is given in Table 18.03.

Planting time. Planting time can greatly influence the occurrence and development of a number of diseases. Early fall planting and warm soil (before the "fly-free" date) promote the development of certain seed rots and seedling blights, Septoria leaf blotches, leaf rust, powdery mildew, Cephalosporium stripe, Helminthosporium spot blotch, wheat streak mosaic, soilborne wheat mosaic, barley yellow dwarf, and wheat spindle streak mosaic. Wheat that is planted early often has excessive foliar growth in the fall, which favors the buildup and survival of leaf rust, powdery mildew, and the Septoria diseases. Disease buildups in the fall commonly favor earlier and more severe epidemics in the spring. Many of these problems can be avoided if planting is delayed until after the "fly-free" date.

Planting after the "fly-free" date is an effective means of limiting the transmission of viruses and yield losses from virus diseases such as wheat streak mosaic and barley yellow dwarf. The cooler temperatures usually limit the activity of mites and aphids that transmit these viruses. Since fall infections result in the greatest yield losses, serious virus problems can be avoided by late planting. See the nearest Extension office for information on fly-free dates.

Seed treatment. Seed treatment trials in Illinois during the past 17 years have increased yields 3 or more bushels per acre by controlling diseases such as bunt, loose smut, Septoria diseases, seed rots, and seedling blights. Failure to control seedling blights may result in serious winterkill of diseased seedlings.

No single fungicide controls all of the diseases just listed. A combination of fungicides is necessary to obtain broad-spectrum seed protection. Since some seedborne pathogens are more difficult to control than others, the full recommended label rate should always be used.

Foliar fungicides. Septoria leaf and glume blotches, powdery mildew, and rusts may occur every year regardless of the precautions taken. These diseases are favored by rainy, windy weather and heavy dews, and are a threat whenever such weather prevails from tillering to heading.

Rusts, powdery mildew, and Septoria diseases can be controlled by timely and proper applications of fungicides. The decision to apply fungicides should be based on the prevalence of disease, disease severity, and the yield potential of the crop. As a general guideline, the upper two leaves (flag and flag-1) should be protected against foliar pathogens since head-filling depends largely on the photosynthetic activity of these two leaves. Loss of leaves below flag-1 usually cause little loss in yield.

Weekly scouting for foliar diseases should begin no later than the emergence of the second node (growth stage 6). If diseases are present at this time and weather conditions favor continued disease development (cool and rainy), a fungicide application should be considered. Be certain that diseases are correctly diagnosed to ensure proper fungicide selection. With protectant fungicides the first application should be at early boot stage followed by a second spray 10 to 14 days later, depending on the weather. Systemic fungicides can be applied when diseases become evident on the upper leaves and provide protection for about 18 days. A protectant fungicide may be needed at heading time for late-season disease control.

Corn disease management

To prevent losses from disease, it is necessary to follow a comprehensive integrated corn disease man-

agement program. Such a program should include the use of disease-resistant hybrids, crop rotations, various tillage practices, balanced fertility, fungicides, insect and weed control, and other cultural practices. These practices should relate to the risk potential of the various diseases and the life cycles of disease-causing organisms (pathogens).

Table 18.04 lists those diseases known to cause yield losses in Illinois and the relative effectiveness of various control measures.

Disease-resistant hybrids. The use of resistant hybrids is the most economical and efficient method of disease control. Although no single hybrid is resistant to all diseases, hybrids with combined resistance to several major diseases are available. Corn producers should select high-yielding hybrids with resistance or tolerance to major diseases in their area.

Crop rotation. Many common pathogens require the presence of a living host crop for growth and reproduction. Examples of such corn pathogens include the leaf diseases ("Helminthosporium" leaf diseases, Physoderma brown spot, Goss's bacterial wilt, gray leaf spot, yellow leaf blight, eyespot) and nematodes. Rotating to nonhost crops (e.g., soybeans, alfalfa, clovers, and canola) "starves out" these pathogens, resulting in a reduction in inoculum levels and the severity of disease. Continuous corn, especially in combination with conservation tillage practices, which promote large amounts of surface residues, may result in severe outbreaks of disease. In such cases it is highly advisable to utilize *all* other disease-control measures.

Tillage. Tillage programs that encourage rapid residue decomposition, before the next corn crop is planted, will help reduce populations of pathogens which overwinter in or on crop debris. Although a clean plowdown is an important disease-control practice, the possibility of soil losses from erosion must be considered. Other control measures can provide effective disease control if conservation tillage is implemented. Examples of diseases partially controlled by tillage include stalk and root rots, "Helminthosporium" leaf diseases, Physoderma brown spot, Goss's bacterial wilt, gray leaf spot, anthracnose, ear and kernel rots, yellow leaf blight, eyespot, and nematodes.

Balanced fertility. Adequate balanced fertility plays an important role in checking the development of such diseases as Stewart's bacterial wilt, seedling blights, leaf blights, smut, stalk rots, ear rots, and nematodes. Diseases are often most severe where there is an excess of nitrogen and a lack of potassium, or both. Healthy, vigorous plants are more tolerant of diseases and better able to produce a near-normal yield.

Foliar fungicides. One or more "Helminthosporium" leaf blights and rust diseases may occur every year regardless of the precautions taken. If extended periods of moist, overcast weather occur before or shortly after tasseling, these diseases may cause losses of 10 to 30 percent. If significant disease occurs earlier than 2 weeks after tasseling, the application of foliar fungicides may be justified, especially in seed production fields. The decision to apply fungicides should be based on the prevalence and severity of leaf diseases. Leaf blights generally are first seen on the lower leaves. Rusts first appear on the upper leaves.

In general, fungicide applications are economically feasible only in seed-production fields. Weekly scouting for "Helminthosporium" leaf blights and rusts should begin at least 2 weeks before tasseling. If diseases are present, and weather conditions favor continued disease development (rainy and overcast), fungicide applications should be considered. Add a label-recommended spreader-sticker (surfactant) to the spray tank to ensure more uniform coverage.

Table 18.04. Corn Diseases That Reduce Yields in Illinois and the Relative Effectiveness of Various Control Measures

Disease	Resistant or tolerant hybrids	Crop rotation	Clean plow-down	Balanced fertility	Fungicides	Other controls and comments
Stewart's bacterial wilt	1			3		Early control of corn flea beetles may be helpful on susceptible hybrids.
Seed rots and seedling blight	2			3	1	Sow injury-free, plump seed. Plant seed in soils 50° to 55°F or above. Prepare seedbed properly and place fertilizer, herbicides, and insecticides correctly.
"Helminthosporium" leaf blights; Northern leaf blight, Northern leaf spot, Helminthosporium leaf spot, Southern leaf blight	1	2	2	3	2	Fungicide applications are generally only justified in seed production fields and only if the lower three leaves up to 2 weeks after tasseling are infected.
Physoderma brown spot	1	3	2			
Yellow leaf blight and eyespot	1	2	1		3	See comments for "Helminthosporium"leaf blights.
Gray leaf spot	2	2	2		3	See comments for "Helminthosporium" leaf blights. Favored by continuous no-till corn production.
Anthracnose	1	2	1	3		
Crazy top and sorghum downy mildew	1	3	3			Avoid low wet areas, and plant *only* downy mildew–resistant sorghums in sorghum-corn rotations. Control of shattercane (an alternate host) is very important.
Goss's bacterial wilt	1	1	2			Rotations of 2 or more years will provide excellent control.
Smut	2	3	3	3		Avoid mechanical injuries to plants. Control insects.
Common and southern rusts	1				3	Fungicides may be justified in seed-production fields.
Stalk rots: Diplodia, Charcoal, Gibberella, Fusarium, Anthracnose, Nigrospora	2	2	2	2		Plant adapted, full-season hybrids at recommended populations and fertility. Control insects and leaf diseases. Survey at 30 to 40 percent moisture to determine potential losses.
Ear and kernel rots: Diplodia, Fusarium, Gibberella, Physalospora, Penicillium[a], Aspergillus[a], Others	2	2	3	3		Control stalk rots and leaf blights. Hybrids that mature in a downward postion with well-covered ears usually have the least ear rot. Ear and kernel rots are increased by bird, insect, and severe drought damage.
Storage molds: Penicillium, Aspergillus, etc.						Store undamaged corn for short periods at 15 to 15.5 percent moisture. Dry damaged corn to 13 to 13.5 percent moisture prior to storage. Low-temperature–dried corn has fewer stress cracks and storage mold problems if an appropriate storage fungicide is used. See a local Extension office for details. Corn stored for 90 days or more should be dried to 13 to 13.5 percent moisture. Inspect weekly for heating, crusting, or other signs of storage molds.
Maize dwarf mosaic	1					Control Johnsongrass and other perennial grasses (alternative hosts) in and around fields.
Wheat streak mosaic	1					Plant winter wheat (an alternative virus host) after the fly-free date and control volunteer wheat. Separate corn and wheat fields.
Nematodes: Lesion, Needle, Dagger, Sting, Stubby-root		2	2	3		Clean plow-down helps reduce winter survival of nematodes. Nematicides may be justified in some situations. See a local Extension office for information on chemical control.

NOTE: Descriptions of these diseases are found in the *Corn Disease Compendium*, published by the American Phytopathological Society, 3340 Pilot Knob Road, St. Paul, MN 55121.

1 = Highly effective control measure; 2 = Moderately effective; and 3 = Slightly effective. A blank indicates no effect.

[a] = Not affected by crop rotation or tillage.

Chapter 19.

On-Farm Research

Many farmers have become actively involved in one or more on-farm research projects. These farmers have become involved with such research and the production of new knowledge for several reasons, including (1) the increasing complexity of crop production practices; (2) the declining support for applied research conducted by universities; and (3) the proliferation of products and practices whose benefits are difficult to demonstrate. Such on-farm research projects have included hybrid or variety strip trials conducted in cooperation with seed companies, tillage comparisons, evaluations of nontraditional additives or other products, and nutrient rate studies, as well as other management practice comparisons.

Setting goals for on-farm research

The stated purpose of most on-farm research is "to prove whether a given product or practice works (normally meaning that it returns more than its cost) on my farm." While this seems like a rather obvious goal, the person conducting or considering conducting on-farm research should understand several implications of such a goal:

1. Like it or not, Illinois farmers operate in a variable environment, with rather large changes in weather patterns from year to year and with differences in soils within and among fields. This forces the operator to modify the above on-farm research goal, from "proving whether [something] works" to "finding out under what conditions [something] works or does not work," or to "finding out how often [something] works." Both of these modifications will require that particular trials be run over a number of years and in a number of fields. The key goal of any applied research project — on-farm or not — is to be able to *predict* what will happen when we use a practice or product in the future. The variable conditions under which crops are produced make such predictions difficult.
2. All fields are variable, meaning that a measurement of anything (such as yield) in a small part of a field (a plot) does not perfectly represent that field, much less the whole farm. Such variability can be assessed using the science of statistics: for example, the statistician might look at the yields of six strips of Hybrid A harvested separately and state, "The average yield of Hybrid A in these strips was 155 bushels per acre. But due to the variability among the harvested strips, it is only 95 percent certain that the actual yield of Hybrid A in this field was between 150 and 160 bushels per acre." In other words, variability means that it is not possible to be completely precise when the effects of a particular treatment are measured. Replicating (treating more than one strip with the same treatment) more times can help narrow the range of unpredictability, but the range will *never* be zero. Some uncertainty will always be present.

If a whole field could be harvested, the exact yield (for that year) would be known, and we wouldn't have to give a range. But with on-farm research, it is necessary to apply treatments to smaller parts of the field since no comparisons are possible if the whole field is treated the same. Suppose the farmer stripped the whole field, with Hybrid A mentioned above in one side of the planter and another hybrid (Hybrid B) in the other side. After harvesting the strips of each hybrid separately, the statistician might be able to state, "Based on the strips chosen to represent Hybrid B, this hybrid yielded 140 bushels per acre, and it is 95 percent certain that the yield of Hybrid B was between 135 and 145 bushels per acre." In this case, since the "confidence intervals" (150 to 160 for Hybrid A; 135 to 145 for Hybrid B) of the two hybrids do not overlap, it is possible to state that

the yields of the two hybrids were *significantly different*. But in this realistic example, note that the yields of the two hybrids differed by 15 bushels per acre, and still the confidence intervals came within 5 bushels of overlapping.

3. Because of the uncertainty, it is necessary to accept that, when measuring yield (or anything else) in applied field research, it is virtually impossible to ever "prove" that some practices or products work or do not work. Even with the most precise field trials done in the most uniform fields, it takes a yield difference of at least 2 or 3 bushels per acre (1 to 2 percent) between treatments to allow the researcher to state with confidence that the treatments produced different yields. As a rather silly example, suppose a farmer went out into a corn field, divided the field into twenty 12-row strips, and carefully cut one plant out of every 500 plants in 10 of the strips, but did nothing to the other 10 strips. It would be absolutely certain that the farmer's treatment (cutting out 0.2 percent of the plants) affected the yield of the treated strips, but it would also be certain that the farmer would not be able to measure a *significant* yield difference between the two treatments, unless perhaps by accident. The variability between strips in a case like this would simply overwhelm a very small but real treatment effect (the physical removal of the plants by the farmer). Similarly, a crop additive or other practice may routinely give small yield increases or decreases, yet never be *proven* to work or not to work.

Types of on-farm trials

The following list comprises different categories of research that have been popular as on-farm projects, along with some comments about each:

1. **Fertilizer rate trials.** Fertilizer is an expensive input, and so rate trials designed to determine a "best" rate, or the effect of reducing rates, have been common. Fertilizer rate is what is called a "continuous" variable — two rates for comparison could differ by 50 pounds per acre, 5 pounds per acre, or 1 pound per acre; the researcher chooses the rates. Whether or not different rates will produce significantly different yields depends, of course, on what rates are selected. This makes the typical "rate reduction" trial difficult to interpret: 140 pounds of nitrogen per acre might or might not produce a different yield from the "normal" 160 pounds of nitrogen per acre, but as was discussed above, a field experiment often will not pick up a small difference. As a result, many rate reduction studies are "successful" in that lower rates do not produce significantly lower yields. But the response to fertilizer rate needs to be generated by using a number of rates — more than just two. And the results should be used to produce a curve showing the response to fertilizer, rather than comparing the yields produced by each rate. Remember that the researcher or operator chooses the fertilizer rates, and the chance of just stumbling on the "best possible" rate is low.

To illustrate, consider the following corn yields produced in a nitrogen (N) fertilizer rate trial:

N rate	*Yield*
0	100
60	142
120	164
180	163
240	140

Many people looking at these numbers would conclude that 120 pounds of N must have been the "best" rate, since it gave the highest yield. Figure 19.01 is another way to look at the same data. The curve, generated by a computer, fits the data quite well in this case.

When the data are presented this way, it is easy to see that the "best" rate was not in fact 120 pounds of nitrogen per acre; the rate that would have given the highest yield was about 150 pounds per acre (actually 148 pounds per acre). It was only by chance that the researcher did not use that (best) rate, but when there is only one best rate (one highest point on the curve), the chance of actually using that best rate is low. (Because N fertilizer has a cost, the best economic rate — that rate producing the highest income — is less than the rate that gives the top yield. How much less depends on the price of N and of corn. In this example, if corn is $2.20 per bushel and N costs $0.15 per pound, then the N rate providing the best return would be about 137 pounds N per acre).

A curve to present data is used for a fertilizer example here, but the same principle applies for any input for which rates are chosen. Examples of such factors include plant population, seed rate, and row spacing.

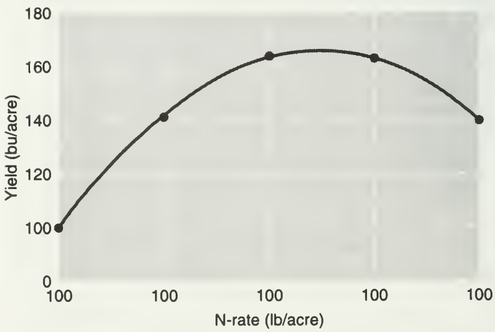


Figure 19.01. A curve fitted to yields from a nitrogen (N) rate trial on corn.

2. **Hybrid or variety comparisons.** Such comparisons are very common and are usually done in cooperation with a seed company. Comparisons have very good demonstration value, and when results are combined over a number of similar trials, they can provide reasonable predictions of future performance of hybrids or varieties. Most of these trials are done as single (unreplicated) strips in a field. It is dangerous to use the results of a single trial to predict future performance. For example, a hybrid that just happens to fall in a wet spot in the field may yield poorly only because of its location, and not because of its genetic potential. Seed companies are increasingly averaging the results of numbers of such strip trials, thereby providing better predictions and making the trials more useful. If participating in such trials, a farmer should be sure to ask the company for results from other locations as well.

   Many people who work with hybrid or variety strip trials are convinced that the effects of variability can be removed by using "check" strips of a common hybrid or variety planted at regular intervals among the varieties being tested. The yields of such check strips are often used to adjust the yields of nearby hybrids or varieties, on the assumption that the check will measure the relative quality of each area in the field, thus justifying inflation of yields in low-yielding parts of the field and deflation of yields in high-yielding parts. If all variation in a field occurred smoothly and gradually across the field, such adjustments would probably be reasonable. But variation does not occur that way, and so it is usually unfair to adjust yields of entries simply because the nearby check yielded differently than the average of all of the checks. The use of such checks can provide some measure of variability in the field, but it also takes additional time and space to plant the trial when checks are used. The only way to know for certain whether or not performance of a variety or hybrid in a strip trial was "typical" is to look at data from a number of such trials to see whether performance is consistent.

3. **Tillage.** Tillage trials are difficult and often frustrating, due in large part to the fact that tillage is really not a very well-defined term. What one farmer may call "reduced tillage," for example, may be very different from what another farmer means when he or she uses the term. The same is true for "conventional tillage," and even for "no-tillage," due to the large number of attachments and other innovations in equipment. Motivations may also differ substantially: while no-tillage versus conventional tillage may seem like a straightforward comparison, an attitude of "I know I can make no-till work" as a basis for doing such a comparison might result in a very different research outcome than if the attitude is "I really don't think no-till yields are as good as in conventional tillage, and I can prove it." This may be an extreme example, but there are indications that tillage trials often are not conducted in a strictly "neutral" research environment.

   It is possible to make on-farm comparisons of tillage practices. Treatments for comparison have to be selected carefully, keeping in mind that "if you already *know* what the results will be, there's very little reason to do research." Because soil type usually affects tillage responses, it is always useful to do tillage trials in several different soil types, either on one farm or among several farms. Replication (to sample soil variation in each field) is also necessary.

4. **Herbicide trials.** Herbicide and herbicide rate trials are subject to large amounts of variation among years and fields due to the fact that soil, weather, crop growth (and sometimes variety), and weed seed supply and growth all can affect the outcome. This makes it very difficult to prove conclusively that a particular herbicide or combination, or a particular rate of herbicide, will be predictably better than another. The use of herbicide additives simply throws another variable into the mix, and makes choosing a "best treatment" even more difficult. Trials in which different herbicides and rates need to be mixed and applied to strips are often very time-consuming.

5. **Management practices.** It can be relatively easy to compare different plant populations or planting rates, though calibration of equipment — knowing how many seeds per acre or pounds per acre of seed are produced by a particular planter or drill setting — can be difficult. Changing the rates also needs to be done during the busy planting season, but this can be made easier if calibration is done beforehand. As discussed above with fertilizer rate trials, two planting rates that differ only slightly may often produce similar yields, and finding a "best" planting rate is difficult. By careful replication of two or three different rates in a number of fields over several years, however, it might be possible (with little risk) to tell whether increased planting rates would increase yields.

6. **"Interaction" and "system" trials.** It is known that a lot of crop production factors *interact*; that is, the response to one factor (plant population, for example) may depend on choices made related to other factors (hybrid, for example). While this is known in principle, it is difficult to design research to help apply this knowledge. The short life of many hybrids and varieties adds to this dilemma: once the research is done to determine the best population for a particular hybrid, that hybrid will likely no longer be available. An alternative is to try to identify hybrids that are "typical" for some characteristic and thereby can represent a lot of other hybrids, both present and future. From a practical standpoint, this is virtually impossible to

do, since it is not possible to know for certain that a hybrid is really typical, and the definition of a typical hybrid changes over time.

Interaction trials, by definition, also require more treatments than do one-factor trials. The simplest interaction trial has four treatments — two levels of one factor times two levels of another. And such a minimal number of treatments may not always tell researchers much. What would be learned, for example, if two plant populations were used with each of two hybrids? Farmers will learn that the hybrids react either the same or differently in relation to plant populations, but a "best" population will not be identified for each hybrid. It may well be more efficient to choose one hybrid as the better of the two, then use three or four different populations to try to see how to increase its yield. In this type of tradeoff, knowledge is limited to one hybrid, but the knowledge becomes much better for that hybrid.

Another example of the problem of measuring the effects of interactions is seen in "systems" research. In many such studies, several factors are changed simultaneously, typically ending up with only two treatments: the "conventional" system and the "new" system. While the simplicity of such trials is appealing, it is often impossible to separate out the effects of any of the changes the farmer made in going to the new system. In other words, it may be possible to compare the overall profitability of the two systems, but it is not possible to *optimize* — choose the best combination of inputs — for the system. Systems trials can be modified by including more treatments and leaving out one component of the new system for each treatment. This will tell how much, if any, each component contributes to the whole system, and will allow the elimination of those changes that are not necessary.

Possible risk associated with on-farm research

On-farm research trials should be selected and designed so that they carry little risk of loss. Many trials, such as those comparing hybrids or varieties, usually include only treatments that yield relatively well — and so represent little risk. It is probably best to avoid entries in such trials that are certain not to perform very well, unless there is special interest, for example, in knowing how modern varieties compare to old varieties.

Some types of trials involve considerable risk of yield loss, and the farmer should at least be aware of this before starting such trials. A good example is nitrogen (N) rate trials designed to include the use of no N as one of the treatments. This treatment is necessary to determine if there is any response to N, but is probably not necessary to find the best rate of N; some N is usually needed for best yields. Thus researchers might use 60, 90, 120, 150, and 180 pounds N per acre in an N rate trial instead of using 0, 50, 100, 150, and 200. This will reduce the loss associated with N rates that are too low. The closer spacing of N rates will — as long as the range is wide enough to include the optimum rate — often do a better job of determining a best rate.

Another example in which untreated "checks" can cause yield losses would be herbicide trials, where the use of no herbicide might cause visually dramatic results, but might not be a practical alternative. As these examples illustrate, it is probably better to restrict most on-farm research treatments to those necessary to identify the most *practical* treatment or rate, rather than to try to cover the whole range of possibilities, including treatments that may never be used on a field scale.

Getting started with on-farm research

While there is a perception that on-farm research takes a lot of time and effort, the very large numbers of variety strip trials prove that farmers will take the necessary time to do such trials if the rewards are sufficient. Such rewards might be material — for example, additional seed often is given to variety strip trial cooperators — or intangible, such as cooperation in a group project that is expected to provide good information useful to all group members.

No matter what the perceptions about time and effort required to conduct on-farm research, it is absolutely essential that the work is clearly specified and assigned before starting the research. To do this, it is most useful to write down everything that will have to be done, when each task must be completed, and who will do the tasks. The important work gets done this way, and participants are able to see beforehand what they will need to do throughout the season to make the project work.

From a practical standpoint, it is best to undertake on-farm research projects that do not interfere greatly with ongoing farming operations, particularly at planting and harvesting times. For example, it may be easier to apply nitrogen rates after planting than to delay planting in order to put on different rates. Trials such as hybrid trials or planting rate trials that must be done at planting time can be planned for fields that are usually ready to plant first (or last), or by trying other ways to work around the main farm operations.

The following steps initiate on-farm research:

1. Decide what type of research is preferred. It is much better if this decision can be made by a group, perhaps a "club," operating with similar goals. It may also be advisable to ask advice from an experienced researcher at this stage. Such researchers may help to ask questions that focus the goal, and they may often know of previous work that might prevent wasted effort.

2. Formulate *specific* objectives. For example, rather than stating, "We want to compare different ways to plant soybeans," make the objectives read, "We want to see how soybeans in 30-inch rows yield compared to those in 7-inch rows."
3. Formulate a research plan to answer questions, including:
   - how many locations and years the research will be conducted;
   - who will actually conduct the comparisons;
   - what soil type restrictions (if any) there will be;
   - what if any equipment, herbicide, or variety restrictions there will be;
   - what data (for example, yield) will be taken; and
   - who will summarize the results.

   Several meetings — field days, progress discussions, results discussions — should be scheduled as part of the plan. Make sure the plan is *practical* — that everyone understands his or her role and has the right equipment to do the work.
4. Pay attention to work underway, thus providing encouragement and accountability to individuals in the group. Field days help do this, along with coffee shop meetings during the season. Set deadlines for the assembly of results, and telephone those who are late to keep everyone on schedule as much as possible.
5. Have an off-season progress meeting, in which results are summarized. Plans can be modified for the next season, but remember that changing treatments or objectives partway through a project is often a fatal blow to the project: the goals become fuzzy, and participants may feel that their work has been wasted. It is certainly inadvisable to stop short of the goal because the first year's results do not "prove" what people had hoped they would prove.
6. Have a final project meeting to present and discuss results from the whole study. While members may choose their own interpretation of the results, such discussions are often very educational and useful. New projects often come from discussions of completed projects.

A word about statistics

While it is almost universally accepted that statistical analysis is required for the interpretation of research results, many farmers and others do not understand how to do this analysis, or why it is necessary. As explained above, statistical analysis involves assessing the variability that is always present, and then making reasonable, mathematics-based assessments as to whether or not observed effects are due to chance or to treatments. When it is concluded that a reasonable chance exists that differences in production outcomes were in fact due to treatments, then it can be said that treatments had a *significant effect.* This conclusion does not mean that it has been *proven* that the treatments caused differences, only that researchers are satisfied that their best guess or assessment is probably correct.

When researchers are unable to draw the conclusion that treatments differed, they say that the treatments were *not significantly different.* Note that this last statement does *not* mean that treatment had no effect. Rather, it simply says that the research trials were not able to detect such an effect. There are two possibilities here: either the treatments really did not have an effect, or they did have an effect, but the experiment was not adequate to detect it. Note the indication above that small effects are very difficult to prove. This is due to the fact that unexplained variation ("background noise") will usually "drown out" small effects.

What can farmers and researchers do when they think treatments should have differed, but the research trials fail to show that they do differ? If this occurs in one trial in one field in 1 year, then the obvious conclusion is that the research needs to be done more often. Due to the nature of statistics, combining the results of a number of trials, even when each trial shows no detectable difference between trials, may well show a significant treatment effect. The more replications (years, fields, strips within fields), the better — provided that each comparison is done carefully and that the conditions of each comparison are reasonably similar. Such combining of results provides much more confidence in making a final conclusion, whether or not it agrees with what research had previously predicted.

Doing statistical analysis is not always simple, and it may often be advisable to work with a researcher to get results analyzed. Remember that statistical analysis cannot improve on the research; no amount of analysis will rescue a trial where the research was done sloppily or with an improper design. Many projects have been made useless by poor designs which do not allow proper analysis — and thus do not allow conclusions supported by solid research.

Above all, keep an open mind: Research designed "to prove what we already know" is not research, but a rather sterile exercise. At the same time, applied research almost always represents "work in progress." Researchers and farmers can benefit a great deal — from the confidence such research in progress provides when deciding to adopt new production practices or to continue more traditional production practices. The increase in knowledge that can be obtained from careful observation of a growing crop and its responses to evolving management practices is a benefit to farming in general and to society at large.

Selected Publications

Readers interested in reading more about a particular topic are referred to these publications, some of which were mentioned in the Handbook. Many of the publications are available from a local Extension office. Many of them are also available for purchase from the Office of Agricultural Communications and Education (OACE), 69 Mumford Hall, 1301 West Gregory Drive, Urbana, Illinois 61801. Addresses for publications from other sources are also indicated.

Chapter 1. Agricultural Climatology

Field Crop Scouting Manual: A Guide to Identifying & Diagnosing Pest Problems, X880b (available from Vocational Agriculture Service, College of Agriculture, University of Illinois, 1401 South Maryland Drive, Urbana, Illinois 61801)

Pest Management & Crop Development Bulletin (distributed weekly throughout the growing season. Subscriptions are available from the University of Illinois, Ag Newsletter Service, 116 Mumford Hall, 1301 West Gregory Drive, Urbana, Illinois 61801)

Chapter 2. Corn

S.R. Aldrich, W.O. Scott, and R.G. Hoeft. *Modern Corn Production, Third Edition*. A & L Publications, Champaign, Illinois

Corn and Sorghum Hybrid Test Results in Illinois (published annually and available each year after harvest from Department of Agronomy, N-307 Turner Hall, University of Illinois, 1102 South Goodwin Avenue, Urbana, Illinois 61801, or a local Extension office)

Corn Planting Date and Plant Population. *Jour. Prod. Agr.* 7:59-62, 1994

Soils of Illinois, B778 (available from OACE)

Uneven Emergence in Corn 1989, NCR-344 (available from OACE)

Chapter 3. Soybeans

Double Cropping in Illinois, C1106 (available from OACE)

Illinois Grower's Guide to Superior Soybean Products, C1200 (available from OACE)

Managing Deficient Soybean Stands, C1317 (available from OACE)

Narrow-Row Soybeans: What to Consider, C1161 (available from OACE)

Performance of Commercial Soybeans in Illinois (available from Department of Agronomy, N-307 Turner Hall, University of Illinois, 1102 South Goodwin Avenue, Urbana, Illinois 61801, or a local Extension office)

Chapter 4. Small Grains

Wheat Performance in Illinois Trials—1990, AG-2054 (available from Department of Agronomy, N-307 Turner Hall, University of Illinois, 1102 South Goodwin Avenue, Urbana, Illinois 61801, or a local Extension office)

Chapter 5. Grain Sorghum

Corn and Sorghum Hybrid Test Results in Illinois, (published annually and available each year after harvest from Department of Agronomy, N-307 Turner Hall, University of Illinois, 1102 South Goodwin Avenue, Urbana, Illinois 61801, or a local Extension office)

Chapter 6. Cover Crops and Cropping System

G.A. Bollero and D.G. Bullock. Cover Cropping Systems for the Central Corn Belt. *Jour. Prod. Agr.* 7:55-58, 1994

Pasture Improvement, Renovation, and Management, AG 2070 (available from Department of Agronomy, N-307 Turner Hall, University of Illinois, 1102 South Goodwin Avenue, Urbana, Illinois 61801, or a local Extension office)

Chapter 7. Alternate Crops

1995 Illinois Agricultural Pest Management Handbook, IPCA-95 (available from OACE)

Chapter 8. Hay, Pasture, and Silage

Hay in 70 Days, C1207 (available from OACE)

Hay That Pays: Hay Marketing, LW8 (available from OACE)

Illinois Seed Law publication—updated as there are changes to the law (available from Illinois Department of Agriculture, Division of Agricultural Industry Regulations, P.O. Box 19281, State Fair Grounds, Springfield, Illinois 62706)

The Land Under Cover: Hay and Pasture Management, LW7 (available from OACE)

1995 Illinois Agricultural Pest Management Handbook, IPCA-95 (available from OACE)

Returning to Grass Roots: Hay and Pasture Establishment, LW6 (available from OACE)

Chapter 9. Seed Production

Illinois Pesticide Applicator Training Manual: Seed Treatment, SP39-4 (available from OACE)

Illinois Seed Law publications—updated as there are changes to the law (available from Illinois Department of Agriculture, Division of Division of Agricultural Industry Regulations, P.O. Box 19281, State Fair Grounds, Springfield, Illinois 62706)

Chapter 10. Water Quality

50 Ways Farmers Can Protect Their Groundwater, NCR522 (available from OACE)

Protecting Water Quality in Illinois, C1315 (available from OACE)

Protecting Your Water Supply from Ag Chemical Backflow, EZ349 (available from OACE)

Water Quality, LW13 (available from OACE)

Chapter 11. Soil Testing and Fertility

Illinois Voluntary Limestone Program Producer Information—annual publication (available from the Illinois Department of Agriculture, Division of Agricultural Industry Regulations, P.O. Box 19281, State Fair Grounds, Springfield, Illinois 62706

Average Organic Matter Content in Illinois Soil Types, Agronomy Fact Sheet SP-36 (available from the Department of Agronomy, N-307 Turner Hall, University of Illinois, 1102 South Goodwin Avenue, Urbana Illinois 61801, or a local Extension office)

Color Chart for Estimating Organic Matter in Mineral Soils, AG-1941 (available from OACE)

Soil Plan (available from IlliNet Software, 548 Bevier Hall, Urbana, Illinois 61801)

Compendium of Research Reports on the Use of Nontraditional Materials for Crop Production (available from Publications Distribution, Printing and Publications Building, Iowa State University, Ames, Iowa 50011 or your local Extension office)

Chapter 12. Soil Management and Tillage Systems

The Residue Dimension—Managing Residue to Control Erosion (CES fact sheets, Land & Water Series No. 9, June 1989. This ongoing series covers a wide range of water quality and soil conservation issues. For more information, write to Land & Water Publications, 305 Mumford Hall, 1301 West Gregory Drive, Urbana, Illinois 61801)

A Farm Machinery Selection and Management Program—J. Siemens, K. Hamburg, and T. Tyrrell (*Jour. Prod. Agr.*, 3:212-219, April-June 1990)

Estimating Your Soil Erosion Loses with the Universal Soil Loss Equation (USLE), C1220 (available from OACE)

Chapter 13. No Tillage

Conservation Tillage Systems and Management: Crop Residue Management with No-Till, Ridge-Till, Mulch-Till, MWPS-45 (available from MidWest Plan Service, Iowa State University, Ames, Iowa 50010-3080

No-Till: Successful No-Till Management, LW16, (available from OACE)

Weed Control Systems for Lo-Till and No-Till, C1306 (available from OACE)

Chapter 14. Water Management

Illinois Drainage Guide, C1226 (available from OACE)

Chapter 15. 1995 Weed Control for Corn, Soybeans, and Sorghum and

Chapter 16. Weed Control for Small Grains, Pastures, and Forages

Herbicide-Resistant Weeds, NCR468 (available from OACE)

1995 Illinois Agricultural Pest Management Handbook, IPCA-95 (available from OACE)

Illinois Drainage Guide, C1226 (available from OACE)

Quackgrass Control in Field Crops, NCR219 (available from OACE)

Weed Control Systems for Lo-Till and No-Till, C1306 (available from OACE)

Weeds of the North Central Region, B772 (available from OACE)

Chapter 17. Management of Field Crop Insect Pests

1995 Illinois Agricultural Pest Management Handbook, IPCA-95 (available from OACE)

Alternatives in Insect Management: Biological and Biorational Approaches, NCR-401 (available from OACE)

Alternatives to Insect Management: Field and Forage Crops, C-1307 (available from OACE)

Biological Control of Insects, E-2453 (available from OACE)

Conservation Tillage Systems and Management: Crop Residue Management with No-Till, Ridge-Till, Mulch-Till, MWPS-45 (available from MidWest Plan Service, Agricultural and Biosystems Engineering Department, 122 Davidson Hall, Iowa State University, Ames, Iowa 50011-3080)

Field Crop Scouting Manual: A Guide to Identifying & Diagnosing Pest Problems, X880b (available from Vocational Agriculture Service, College of Agriculture, University of Illinois, 1401 South Maryland Drive, Urbana, Illinois 61801)

Weed Control/ Herbicide-Resistant Weeds, NCR-468 (available from OACE)

Insect Pest Management for Field and Forage Crops, J1-95 (available from OACE)

Pest Management & Crop Development Bulletin (distributed weekly throughout the growing season. Subscriptions are available from the University of Illinois, Ag Newsletter Service, 116 Mumford Hall, 1301 West Gregory Drive, Urbana, Illinois 61801)

Soybean Insects: Identification and Management in Illinois, B-773 (available from OACE)

Chapter 18. Disease Management for Field Crops

1995 Illinois Agricultural Pest Management Handbook, IPCA-95 (available from OACE)

Various reports on plant diseases (available from Plant Pathology, University of Illinois, 1101 South Goodwin, Urbana, Illinois 61801)

New!

Revised for 1995!

1995 Illinois Agricultural Pest Management Handbook

Protect your crops with timely recommendations from Illinois pesticide specialists. The **1995 Illinois Agricultural Pest Management Handbook** contains guidelines for insect, weed, and disease management and provides information on pesticide application and equipment.

The **1995 Illinois Pest Management Handbook** includes

- A new chapter on weed resistance to herbicides not in previous editions
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- Current advice on management of adult corn root-worms to prevent egg-laying
- Recommended economic thresholds and scouting procedures for key insect pests
- New table on rainfall periods for postemergence herbicides
- New table on cabbage varities resistant to thrips

IPCA-95

1995 Illinois Agricultural Pest Management Handbook

$15.00

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The 69th Annual Summary of Illinois Farm Business Records	C1334		4.00	
Herbicide-Resistant Weeds	NCR468		2.00	
50 Ways Farmers Can Protect Their Groundwater	NCR522		5.00	
Weed Control Systems for Lo-Till and No-Till	C1306		1.50	
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A Comprehensive Look at Farm Performance

The **69th Annual Summary of Illinois Farm Business Records** presents 1993 income and expenses reported by over 7,000 participating Illinois farmers — including nearly 20 percent of all farms of 500 acres or more.

The summary includes an analysis of recent changes in farm income for grain and livestock enterprises throughout Illinois. Comprehensive tables show average 1993 results by farm size, region, type of operation, and soil-fertility rating.

Designed for Easy Comparison

You can use these results to compare your own operation with hundreds of others similar to yours. Complete, detailed tables show total and per-acre average costs and investments for a wide range of expenses, including

- Seed, pesticide, and fertility
- Power and equipment
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And there's space in each table to insert your own figures for comparison.

Information You Can Use

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Order Your Copy Today

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C1334. 1994. 40 pages, soft cover, 8 1/2" x 11". $4.00

Other Publications Available

Herbicide-Resistant Weeds
$2.00 NCR468

Provides information on such topics as selection of resistant weed biotypes; selection intensity; herbicide factors that increase selection intensity; and weed characteristics that favor resistance. 1994. 10p.

Weed Control Systems for Lo-Till and No-Till
$1.50 C1306

Suggests general weed control methods for conservation tillage systems. Describes lo-till and no-till systems that help conserve soil, fossil fuels, trips over the field, and equipment expense. 1993. 12p.

50 Ways Farmers Can Protect Their Groundwater
$5.00 NCR 522

Provides practical ideas on how midwestern farmers can protect groundwater and cut costs by reducing chemical use and applying chemicals more efficiently. Also features profiles of farmers who have experience with management practices described in the book. 1993. 150p.

Get Your Copy of the 1995 Illinois Urban Pest Management Handbook!

The **1995 Illinois Urban Pest Management Handbook** is one of the few pest control publications for the Midwest produced *annually*. Geared toward horticulture and ornamental professionals, this handbook contains the University of Illinois Cooperative Extension Service control recommendations for insects, weeds, and diseases for commercial care of trees, shrubs, and other woody ornamentals; flowers and other non-woody ornamentals; greenhouses and interiorscapes; turfgrass; aquatic areas; golf courses; and rights-of-way. In addition, homeowner and residential control recommendations for landscape, household pests, vegetable gardens, and fruit plantings are included. The **1995 Illinois Urban Pest Management Handbook** also provides up-to-date information on the following:

- **Rootworm damage in corn after soybeans**
- **Furadan 4F for rootworm control**
- **Aerially applied insecticides to prevent egg laying by corn rootworm adults**
- **Recordkeeping requirements for restricted-use pesticides**
- **Minimizing bee, fish, and wildlife losses from pesticides**
- **Pesticides registered in Illinois for a variety of growing plants**
- **Selecting the right product for the right application**
- **How to apply pest control chemicals for safe, effective results**
- **Control measures that don't require using pesticides**

Although the handbook doesn't include all pesticides registered for urban use, when- ever possible it suggests effective pesticides that do not present an undue hazard to the user or to the environment.

You can depend on this up-to-date, objective information from the University of Illinois Cooperative Extension Service. Order your copy of the **1995 Illinois Urban Pest Management Handbook,** which costs only $10.00. You may use the order form or call (217)333-2007. As with all Cooperative Extension Service publications, there are no additional postage and handling costs.

Publication Title	Pub. #	No. of Copies	Price per Copy	Total Cost
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Useful Facts and Figures

To convert column 1 into column 2, multiply by	Column 1	Column 2	To convert column 2 into column 1, multiply by
	Length		
0.621	kilometer, km	mile, mi	1.609
1.094	meter, m	yard, yd	0.914
0.394	centimeter, cm	inch, in.	2.54
16.5	rod, rd	feet, ft	0.061
	Area		
0.386	kilometer^2, km^2	mile^2, mi^2	2.59
247.1	kilometer^2, km^2	acre, acre	0.004
2.471	hectare, ha	acre, acre	0.405
	Volume		
0.028	liter	bushel, bu	35.24
1.057	liter	quart (liquid), qt	0.946
0.333	teaspoon, tsp	tablespoon, tbsp	3
0.5	fluid ounce	tablespoon, tbsp	2
0.125	fluid ounce	cup	8
29.57	fluid ounce	milliliter, ml	0.034
2	pint	cup	0.5
16	pint	fluid ounce	0.063
	Mass		
1.102	ton (metric)	ton (English)	0.907
2.205	kilogram, kg	pound, lb	0.454
0.035	gram, g	ounce (avdp.), oz	28.35
	Yield		
0.446	ton (metric)/hectare	ton (English)/acre	2.24
0.891	kg/ha	lb/acre	1.12
0.891	quintal/hectare	hundredweight/acre	1.12
0.016	kg/ha-corn, sorghum, rye	bu/acre	62.723
0.015	kg/ha-soybean, wheat	bu/acre	67.249
	Temperature		
$(9/5 \cdot C)+32$	Celsius	Fahrenheit	$5/9(F-32)$

Plant Nutrition Conversion

P(phosphorus) × 2.29 = P_2O_5
K(potassium) × 1.2 = K_2O

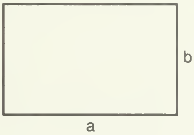
P_2O_5 × .44 = P
K_2O × .83 = K

ppm × 2 = lb/A (assumes that an acre plow depth of 6⅔ inches weighs 2 million pounds)

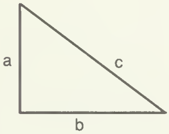
Useful Equations

$$\text{Speed (mph)} = \frac{\text{distance (ft)} \times 60}{\text{time (seconds)} \times 88}$$

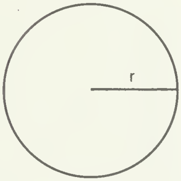
1 mph = 88′/min



Area = a × b



Area = ½ (a × b)



Area = πr^2
$\pi = 3.1416$

$$\text{lb}/100\ \text{ft}^2 = \frac{\text{lb/acre}}{435.6}$$

$$\text{Example: 10 tons/acre} = \frac{20{,}000\ \text{lb}}{435.6} = 46\ \text{lb}/100\ \text{ft}^2$$

$$\text{oz}/100\ \text{ft}^2 = \frac{\text{lb/acre}}{435.6} \times 16$$

$$\text{Example: 100 lb/acre} = \frac{100}{435.6} \times 16 = 4\ \text{oz}/100\ \text{ft}^2$$

$$\text{tsp}/100\ \text{ft}^2 = \frac{\text{gal/acre}}{435.6} \times 192$$

$$\text{Example: 1 gal/acre} = \frac{1}{435.6} \times 192 = .44\ \text{tsp}/100\ \text{ft}^2$$

Water weight = 8.345 lb/gal
Acre-inch water = 27,150 gal